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Spatial Patterns and Temporal Variability in Water Quality from City of Albuquerque Drinking-Water Supply Wells and Piezometer Nests, with Implications for the Ground-Water Flow System

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Multiply	By	To obtain
	Length	
inch	2.54	centimeter
inch	25.4	millimeter
foot	0.3048	meter
mile	1.609	kilometer
	Area	
acre	0.4047	hectare
acre	0.4047	square hectometer
acre	0.004047	square kilometer
square mile	259.0	hectare
square mile	2.590	square kilometer
	Volume	
acre-foot	1.233	cubic meter
acre-foot	0.001233	cubic hectometer
	Flow rate	
acre-foot per year	1.233	cubic meter per year
acre-foot per year	0.001233	cubic hectometer per year
foot per day	0.3048	meter per day
foot per second	0.3048	meter per second
cubic foot per second	0.02832	cubic meter per second

Temperature in degrees Fahrenheit (°F) or degrees Celsius (°C) may be converted as follows:

$$°C = (°F - 32) / 1.8$$

$$°F = (1.8 \times °C) + 32$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Elevation, as used in this report, refers to distance above sea level.

SPATIAL PATTERNS AND TEMPORAL VARIABILITY IN WATER QUALITY FROM CITY OF ALBUQUERQUE DRINKING-WATER SUPPLY WELLS AND PIEZOMETERS NESTS, WITH IMPLICATIONS FOR THE GROUND-WATER FLOW SYSTEM

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ABSTRACT

Water-quality data for 93 City of Albuquerque drinking-water supply wells, 7 deep piezometer nests, and selected additional wells were examined to improve understanding of the regional ground-water system and its response to pumpage. Plots of median values of several major parameters showed discernible water-quality differences both areally and with depth in the aquifer. Areal differences were sufficiently large to enable delineation of five regions of generally distinct water quality, which are consistent with areas of separate recharge defined by previous investigators. Data for deep piezometer nests indicate that water quality generally degrades somewhat with depth, except in areas where local recharge influenced by evapotranspiration or contamination could be affecting shallow water.

The orientations of the five water-quality regions indicate that the direction of ground-water flow has historically been primarily north to south. This is generally consistent with maps of predevelopment hydraulic heads, although some areas lack consistency, possibly because of differences in time scales or depths represented by water quality as opposed to hydraulic head. The primary sources of recharge to ground water in the study area appear to be mountain-front recharge along the Sandia Mountains to the east and the Jemez Mountains to the north, seepage from the Rio Grande, and infiltration through Tijeras Arroyo. Elevated concentrations of many chemical constituents in part of the study area appear to be associated with a source of water having large dissolved solids, possibly moving upward from depth.

Hydraulic-head data for deep piezometer nests indicate that vertical head gradients differ in direction and magnitude across the study area. Hydraulic-head gradients are downward in the central and western parts of the study area and upward across much of the eastern part, except at the mountain front. Water-quality data for the piezometers indicate that the ground water is not well mixed, even in areas of large vertical gradients.

Water levels in most piezometers respond to short-term variations in ground-water withdrawals and to the cumulative effect of long-term withdrawals throughout the area. In most piezometers screened below the water table, water levels respond clearly to seasonal variations in ground-water withdrawals. Water levels decline from about April through July and rise from about September through January. Water levels seem to be declining in most piezometers at a rate less than 1 foot per year.

Water-quality data for unfiltered samples collected over a 10-year period from 93 City of Albuquerque drinking-water supply wells were examined for variability and temporal trends in 10 selected parameters. Variability generally was found to be greatest in the Western and Northeast water-quality regions of the study area. For the 10 parameters investigated, temporal trends were found in 5 to 57 wells. Dissolved-solids, sodium, sulfate, chloride, and silica concentrations showed more increasing than decreasing trends; calcium, bicarbonate, and arsenic concentrations, field pH, and water temperature showed more decreasing than increasing trends. The median magnitudes of most of these trends over a 1-year period were not particularly large (generally less than 1.0 milligram per liter), although the magnitudes for a few individual wells were significant.

For the 10 parameters investigated, correlations with monthly pumpage volumes were found in 10 to 32 wells. Calcium and sulfate concentrations, field pH, and water temperature

showed more positive than negative correlations with monthly pumpage; dissolved-solids, sodium, bicarbonate, chloride, silica, and arsenic concentrations showed more negative than positive correlations. An increase in pumpage in an individual well appears to increase the contribution of water from shallower parts of the aquifer in some areas and from deeper parts in others.

Patterns observed in the spatial distributions of water-quality parameters provide possible insight into the influences of regional ground-water withdrawals on ground-water flow. Per well, the Western and Northeast regions had the most parameters showing large variability, temporal trends, and correlation with monthly pumpage volumes. In both regions, local pumping stresses appear to be a significant factor in the quality of pumped waters. In other regions, temporal trends were common, but correlations with monthly pumpage were not. A factor that affects essentially all wells, such as regional drawdown of the water table, could be an important cause of the observed water-quality variation in these regions.

INTRODUCTION

A thorough understanding of the ground-water flow system in the Albuquerque area (fig. 1) is essential for planning future use of the ground-water resources of the region. Most previous investigations in the area have focused on ground-water levels, aquifer tests, geologic structure of the Middle Rio Grande Basin, and lithology of Santa Fe Group deposits. Only a limited number of investigators have studied the extent to which hydrochemical data can provide additional insight into the physical aspects of the hydrogeologic system. This study, which was conducted in cooperation with the City of Albuquerque (City), uses the large quantity of water-quality data that have been collected in the Albuquerque area to improve understanding of the flow system in the area. The available data include more than 151,000 individual measurements of chemical and physical parameters for City drinking-water supply wells that span a 10-year period. Bexfield and others (1999) described the methods of collection and analysis of these water-quality data and provided statistical summaries. These data are particularly useful for identifying temporal changes in water quality and determining relations between water quality and selected factors, such as the volume of ground-water pumpage.

In addition to the long-term water-quality data that have been collected for City drinking-water supply wells, new data also have recently become available for deep piezometer nests drilled in various parts of the city since 1996. These piezometer nests have enabled collection of water-quality and water-level data from multiple depths, extending from the water table to below the production level of City drinking-water supply wells. The water-quality data for these piezometer nests are useful for examining variability in water quality with depth and can provide information about the degree of vertical mixing in the aquifer and possible reasons for vertical differences in water quality. Piezometer water-level data provide information about the ground-water flow system and how it responds to ground-water pumping.

Purpose and Scope

This report examines water-quality data for City drinking-water supply wells and deep piezometer nests to improve understanding of the regional geohydrologic framework. Water-level data for the deep piezometer nests also are examined to better define the ground-water flow system and its response to ground-water pumpage. Examination of water-quality data is limited to a subset of 10 water-quality parameters (dissolved solids, calcium, sodium, bicarbonate, sulfate, chloride, silica, arsenic, field pH, and water temperature) selected to represent major-element and trace-element chemistry and physical properties of water from the aquifer. These 10 water-quality parameters are examined for spatial patterns, both areally and with depth, and implications for ground-water source areas and flow paths. Long-term data for 1988-97 from City drinking-water supply wells are tested for variability, temporal trends, and relations to ground-water pumpage.

Previous Investigations

Thorn and others (1993) provided a comprehensive compilation and discussion of the geohydrologic framework and hydrologic conditions of the Middle Rio Grande Basin, also known as the Albuquerque Basin. Therefore, a listing of all previous

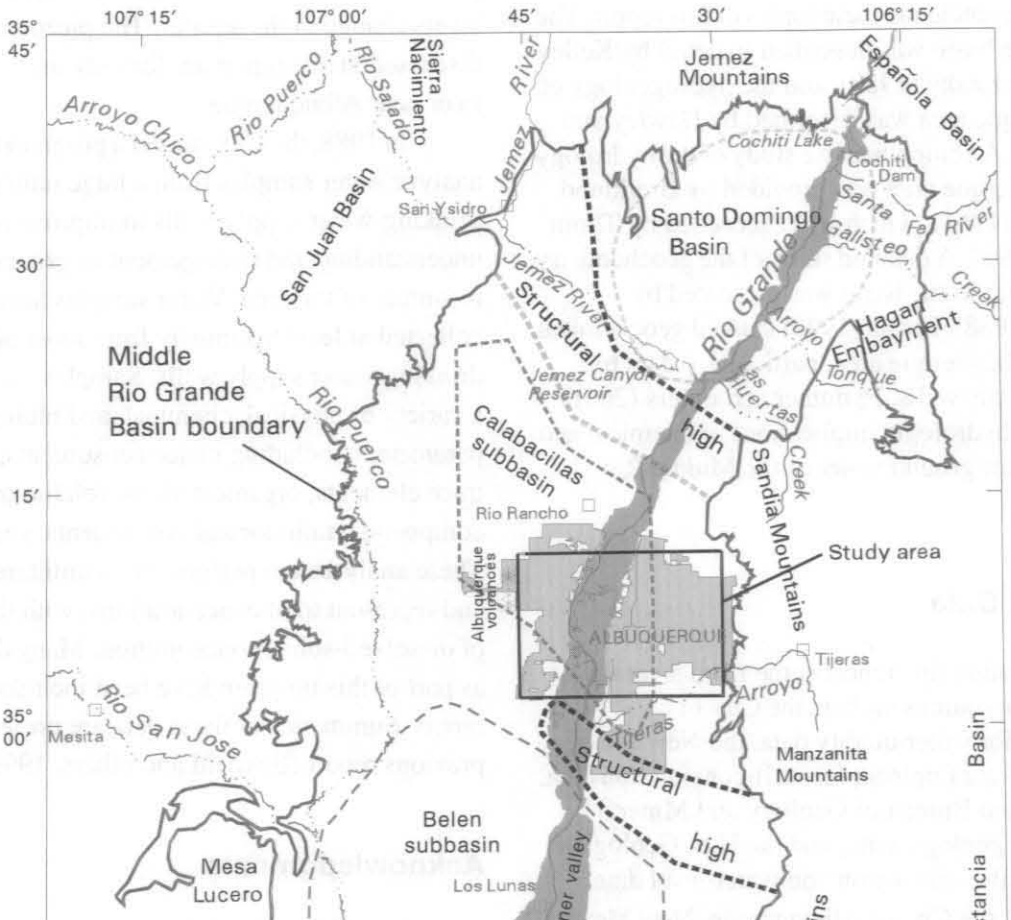


Figure 1. Selected features of the study area and the Middle Rio Grande Basin (generalized structural features modified from Grauch and others, 1999).

investigations that contributed to current knowledge is not repeated here. However, a few investigations are especially relevant to the main topics of this report. The geology of the basin was described in detail by Kelley (1977) and Lozinsky (1988), and the hydrogeology of the Albuquerque area was described by Hawley and Haase (1992). A comprehensive study of the hydrology of the Albuquerque area was provided by Bjorklund and Maxwell (1961), which was succeeded by Thorn and others (1993). A detailed study of the geochemistry of ground water in the basin was presented by Anderholm (1988). Logan (1990) studied geochemical data in the Albuquerque area, particularly data for municipal-supply wells. Plummer and others (2001) described the hydrologic implications of chemical and isotopic data for ground water of the Middle Rio Grande Basin.

Sources of Data

Data used in this report come from a variety of sources. These sources include the City of Albuquerque for water-quality data, the New Mexico Office of the State Engineer for well-construction data, the New Mexico Bureau of Geology and Mineral Resources for geologic data, and the U.S. Geological Survey for well-construction and water-level data.

In 1996, the City of Albuquerque, New Mexico Office of the State Engineer, Bernalillo County, and the U.S. Geological Survey started a program to install deep piezometer nests in the Middle Rio Grande Basin (fig. 2). These nests generally contain three piezometers screened (open to the aquifer) at different depths. In general, the screens are located at the water table (top of the zone of saturation), near the middle of the pumped zone of the closest City drinking-water supply wells, and near the bottom of or below the pumped zone. The screens at the water table are as long as 100 feet, whereas the screens in the other zones are generally 5 to 10 feet long. Most of these piezometer nests are located at least 1 mile from City drinking-water supply wells to enable collection of data representing regional conditions rather than local conditions affected by an individual large-capacity well. Water samples currently (2001) are collected by the City of Albuquerque Environmental Health Department at regular intervals from most of these piezometers to characterize vertical water-quality variations in the aquifer. These water samples are passed through a filter with a 0.45-micron sieve size. Water levels have been measured in most of these piezometers since construction to document how water levels change in the aquifer. The piezometer data discussed in this report are for only those nests located in or near Albuquerque.

In 1988, the City started a program to collect and analyze water samples from a large number of its drinking-water supply wells to improve the understanding and management of ground-water resources of the area. Water samples have been collected at least biannually from most of these drinking-water supply wells. Samples are analyzed for a variety of physical, chemical, and biological parameters, including major constituents, nutrients, trace elements, organic carbon, volatile organic compounds, radiological constituents, and bacteria. These analyses are performed on unfiltered samples and represent total concentrations, with the exception of dissolved-solids concentration. Many data collected as part of this program have been included in this report. Summaries of these data are presented in a previous report (Bexfield and others, 1999).

Acknowledgments

The authors thank the management of the City of Albuquerque Public Works and Environmental Health Departments for enabling the collection of most of the data used in this study. In particular, these departments have facilitated collection of geophysical-log data and water-quality data for City drinking-water supply wells and deep piezometer nests as well as the drilling of deep piezometer nests and monitoring of ground-water levels in the various piezometer completions.

This investigation would not have been possible without the contributions of several individuals with the City of Albuquerque. In particular, Bill Lindberg with the Water Utility Division not only provided access to the City of Albuquerque water-quality database, but also shared the insights he gained from years of work with the database. Doug Earp with the City's Environmental Health Department is also acknowledged for making available the water-quality data for samples that he and his staff collected from the City's deep piezometer nests.

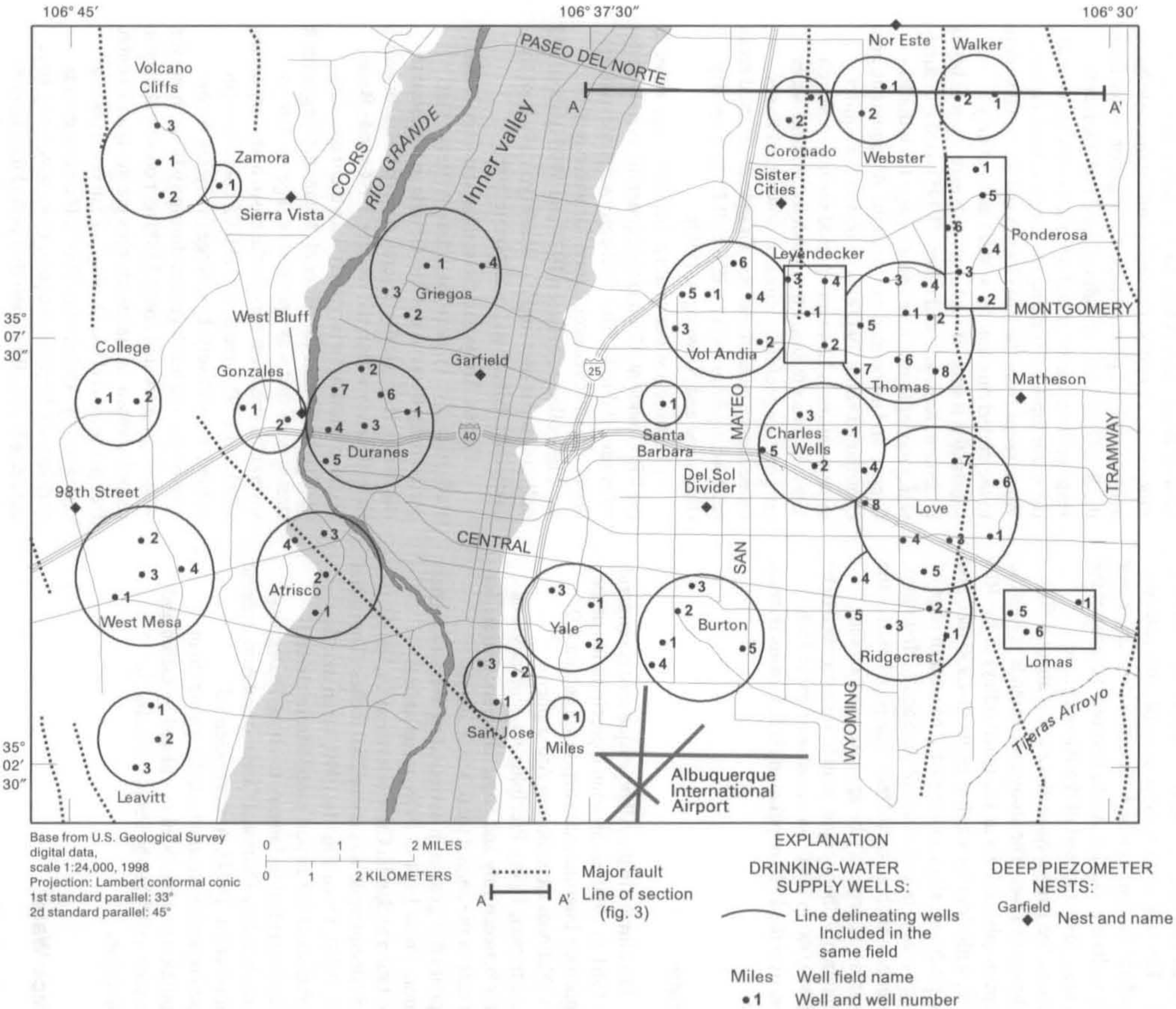


Figure 2. Locations of City of Albuquerque drinking-water supply wells, deep piezometer nests, and suspected major faults (from Mark Hudson and Scott Minor, U.S. Geological Survey, written commun., 1999).

DESCRIPTION OF THE STUDY AREA

The study area covers about 161 square miles in the Middle Rio Grande Basin of central New Mexico (fig. 1). The area encompasses most of Albuquerque, particularly the part in which the city's drinking-water supply wells are located. At the northwest corner of the study area, just northeast of the Albuquerque volcanoes, the land-surface elevation is about 5,600 feet above sea level. The study area extends across the flood plain (also known as the inner valley) of the Rio Grande, with elevations as low as about 4,930 feet, and up the piedmont slope to the east. The eastern edge of the study area is near the base of the Sandia Mountains, at elevations of about 6,100 feet. The population of the study area can probably be approximated by the population of Albuquerque, which was estimated to be about 449,000 in 2000, an increase of about 16.6 percent over the 1990 population (U.S. Census Bureau, 2001).

Climate

The climate in the Albuquerque area is semiarid. From 1961 to 1990, mean annual precipitation at the Albuquerque International Airport was about 8.9 inches (National Oceanic and Atmospheric Administration, 1994). Precipitation generally was greatest between July and September, accounting for about half of the annual total. Mean annual precipitation is greater in surrounding areas of higher elevation. From 1954 to 1978, mean annual precipitation at Sandia Crest (elevation 10,680 feet) east of Albuquerque was about 22.9 inches (Thorn and others, 1993). From 1961 to 1990, mean monthly temperatures at the airport ranged from about 34 degrees Fahrenheit in January to about 78 degrees Fahrenheit in July (National Oceanic and Atmospheric Administration, 1994). Annual potential evapotranspiration is substantially greater than precipitation and has been calculated by Gabin and Lesperance (1977) to be about 48 inches in Albuquerque.

Surface Water

The Rio Grande is the main surface drainage for the study area and the entire Middle Rio Grande Basin (fig. 1). Since 1973, discharge of the Rio Grande has been regulated at the north end of the basin by Cochiti Dam. The mean annual discharge of the Rio Grande at Albuquerque for water years 1974-98 was about 1,450 cubic feet per second (Ortiz and others, 1999). The Rio Grande flood plain in the study area is about 3 to 4 miles wide. A system of canals and drains distributed across the flood plain transports irrigation water from the Rio Grande to agricultural land and intercepts seepage from the river and irrigated fields to prevent the water table from rising too close to land surface. Water seeps from the Rio Grande and the canal system to the underlying aquifer system and is likely a substantial source of recharge, although its quantity is uncertain. Kernodle and others (1995) used a ground-water model to estimate that seepage from the Rio Grande and associated canals in the Albuquerque area contributed about 79,000 acre-feet to the aquifer system during a 12-month period ending in March 1994. In a recent study that modeled ground-water temperature profiles, estimated downward fluxes immediately beneath the Rio Grande in selected areas near Albuquerque were 0.058 to 0.12 foot per day (Bartolino and Niswonger, 1999).

Historical water-quality data show that water in the Rio Grande at Albuquerque generally is suitable for most uses (table 1). The discharge-weighted average dissolved-solids concentration for water-quality samples collected between 1971 and 1995 is about 212 milligrams per liter (mg/L). Water typically is of the calcium/carbonate and bicarbonate type.

Tijeras Arroyo, in the southeast corner of the study area (fig. 1), is an intermittent stream that periodically flows to the Rio Grande in response to storm runoff. Typically, Tijeras Arroyo flows for only a short distance within the Middle Rio Grande Basin because infiltration increases with the increasing thickness of basin-fill material. Mean discharges for a stream gage that was operated on Tijeras Arroyo several hundred feet outside the basin boundary during 1990 and 1991 were 0.14 and 0.05 cubic foot per second, respectively. Discharge in Tijeras Arroyo apparently was much greater during 1944-48, however, when a gage located about 1,000 feet outside the basin recorded mean annual discharges greater than 13 cubic feet per second (U.S. Geological Survey, 1960), as discussed by Anderholm (2001). If discharge was consistently larger in the past, more water may have infiltrated annually during that period than does so currently. Surface-water samples collected between 1989 and 1991 at the gage outside the basin boundary indicate that water in Tijeras Arroyo is more mineralized than water in the Rio Grande (table 1).

Table 1. Discharge-weighted average concentrations of selected constituents in area surface water

[All concentrations are dissolved. mg/L, milligrams per liter; µg/L, micrograms per liter; $CaCO_3$, calcium carbonate]

Constituent	Site and years of record: Rio Grande at Albuquerque (1971-95)	Tijeras Arroyo above Four Hills (1989-91)
Dissolved solids (mg/L)	212	494
Calcium (mg/L)	37.1	102
Magnesium (mg/L)	6.42	21.2
Sodium (mg/L)	21.7	39.1
Potassium (mg/L)	2.97	5.47
Alkalinity (mg/L as $CaCO_3$)	97.1	199
Sulfate (mg/L)	58.0	105
Chloride (mg/L)	9.2	82.0
Silica (mg/L)	18.4	15.6
Arsenic (µg/L)	2.85	1.0

The discharge-weighted average dissolved-solids concentration in Tijeras Arroyo was about 494 mg/L, and the average concentrations of calcium, magnesium, sodium, potassium, alkalinity, sulfate, and chloride were all substantially larger than those in the Rio Grande. Water was typically of the calcium/mixed anion type. However, whether the quality of water in Tijeras Arroyo during times of greater discharge, such as during the 1940's, was similar to current quality is unknown.

Hydrogeology

Structural Geology

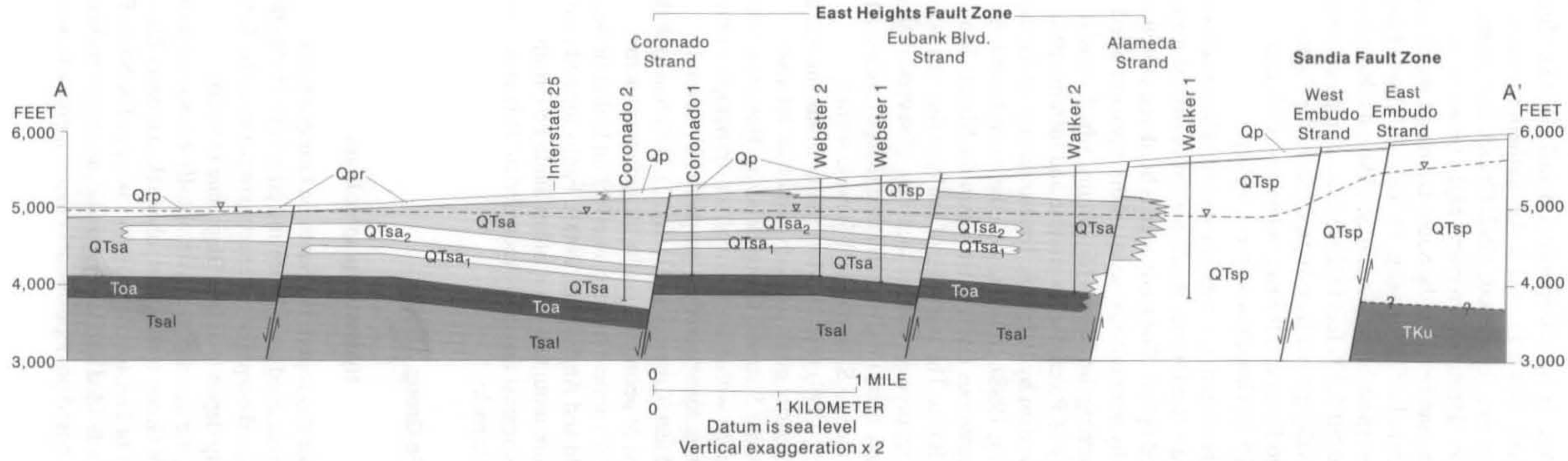
The study area is located in the Rio Grande Rift, a depression more than 600 miles long formed by crustal extension that began in late Oligocene time (Lozinsky, 1988). This depression includes a series of structural and physiographic basins, the sediments of which are hydraulically connected. The Middle Rio Grande Basin is the third largest of these basins (Thorn and others, 1993) and includes young faulting, recent volcanism, and thick basin fill, as are typical of basins in the rift (Lozinsky, 1988). As defined, the Middle Rio Grande Basin includes the Santo Domingo Basin defined by Kelley (1952) in the north (fig. 1) and the Calabacillas and Belen subbasins formed by a northern, eastward-dipping half-graben and a southern, westward-dipping half-graben (Lozinsky, 1988). Much of the study area is located in the northern subbasin. Recent studies (Heywood, 1992; Grauch and others, 1999) have identified structural highs between the subbasins and between the Santo Domingo Basin and the northern half-graben (fig. 1). Santa Fe Group basin fill covers these highs (Lozinsky, 1988); its thickness can be about 5,000 feet in these areas compared with substantially greater than 10,000 feet in the Santo Domingo Basin and the two subbasins (Cole and others, 1999; Grauch and others, 1999).

The eastern and western structural boundaries of the Middle Rio Grande Basin consist mostly of major faults and uplifts. The study area is bordered closely to the east by the fault-line scarp of the eastward-tilted uplift forming the Sandia Mountains, which consist primarily of Precambrian granitic and metamorphic rocks overlain by Paleozoic limestone and sandstone (Lozinsky, 1988). In addition to the basin-bounding faults, numerous faults exist within the Middle Rio Grande Basin. The mapping of faults in the area is a continuing process, but the locations of several major faults have been firmly established (Mark Hudson and Scott Minor, U.S. Geological Survey, written commun., 1999) (fig. 2). Most faults within the basin trend primarily north to south and offset relatively homogenous Santa Fe Group deposits. However, some major faults within the basin offset stratigraphic units of differing hydrogeologic properties by several hundred feet (Connell, 1997) (fig. 3). Differences in the thickness of permeable basin-fill sediments across these faults appear to have an effect on hydraulic head (Bexfield and Anderholm, 2000). Faults located near the eastern mountain front offset Santa Fe Group deposits against assorted Precambrian, Paleozoic, or Mesozoic rocks.

Santa Fe Group Aquifer

Hydrostratigraphic Units

For this report, the Santa Fe Group aquifer system is defined as in Thorn and others (1993). By this definition, the aquifer system consists of both the Santa Fe Group deposits of late Oligocene to middle Pleistocene age and the hydraulically connected post-Santa Fe Group flood-plain, channel, and basin-fill deposits of Pleistocene to Holocene age. The Santa Fe Group is divided into lower, middle, and upper sections that are based on depositional environments and age.



EXPLANATION

Qrp: Los Padillas Formation (historic to uppermost Pleistocene)--Unconsolidated to poorly consolidated, fine- to coarse-grained sand and rounded gravel with interbeds of fine-grained sand, silt, and clay derived from the Rio Grande

Qp: Piedmont and stream alluvium, undivided (historic to middle Pleistocene)

Qpr: Fluvial deposits, piedmont alluvium, and stream alluvium, undivided (historic to middle Pleistocene)

QTsa: Axial-fluvial deposits of the ancestral Rio Grande, undivided (lower Pleistocene to Pliocene)
- $QTsa_2$: Upper sandy mudstone marker bed (Pliocene)
- $QTsa_1$: Lower sandy mudstone marker bed (Pliocene)

QTsp: Piedmont deposits (lower Pleistocene to Miocene)

Toa: Arroyo Ojito Formation, Atrisco Member (Pliocene)--Moderately to well consolidated, locally cemented succession of fine-grained silty sandstone and mudstone

Tsal: Lower fluvial deposits (Pliocene to upper Miocene)

TKu: Lower Tertiary and Cretaceous sedimentary rocks, undivided (Paleogene-Cretaceous)

Figure 3. Geologic section along Paseo del Norte in northern Albuquerque (modified from Connell, 1997). See figure 2 for section location.

The general descriptions of these sections given here are from Hawley and Haase (1992), who discussed the lithofacies of the basin in much greater detail. The lower Santa Fe Group, which ranges from less than 1,000 feet thick near the eastern basin margin to about 3,500 feet thick through the center of the study area, is dominated by intertonguing piedmont-slope, eolian, and fine-grained basin-floor deposits that represent deposition in an internally drained basin. The middle Santa Fe Group is as much as about 9,000 feet thick through the center of the study area and consists of piedmont-slope deposits and fluvial sediments deposited by major fluvial systems from the north, northeast, and southwest. These systems probably terminated in playa lakes in the southern part of the basin. The upper Santa Fe Group, which is between 500 and 1,500 feet thick throughout most of the study area, is the most permeable and consists of piedmont-slope and fluvial basin-floor deposits. Through the center of the study area, the thickness of the entire Santa Fe Group generally exceeds 10,000 feet. Post-Santa Fe Group valley fill is as much as about 130 feet thick. The Albuquerque volcanic field near the western edge of the city (fig. 1) was emplaced during middle to late Pleistocene time.

Recent studies (Connell and others, 1998; Stone and others, 1998) have delineated the middle from the upper Santa Fe Group deposits using a distinctive red-brown clay layer that is easily discerned in geophysical logs. This layer was named the Atrisco member of the Arroyo Ojito Formation (Toa in fig. 3) by Connell and others (1998). Stratigraphic correlations presented in both studies, which used data obtained primarily from City wells, show the Atrisco member dipping to the east beneath Albuquerque (fig. 3). These correlations indicate that most City drinking-water supply wells east of the Rio Grande inner valley (fig. 2) are screened almost entirely in the upper Santa Fe Group (above the Atrisco member). Wells in the inner valley appear generally to be screened primarily in the upper Santa Fe Group and only partly in the middle Santa Fe Group, whereas most wells to the west appear to be screened mainly in the middle Santa Fe Group.

Hawley and Haase (1992) found that the bulk composition of basin fill in the Albuquerque area was approximately 60 percent granitic-metamorphic detritus of Precambrian derivation, 30 percent volcanic detritus of middle Tertiary derivation, and less than 10 percent sedimentary detritus of Paleozoic or Mesozoic derivation. Below the northeast part of Albuquerque, sediments at depths of about 200 to 3,200 feet were described as volcanic rich; the volcanic material was thought to be derived from the Jemez Mountains and other sources farther to the north. Clay minerals present in mudrocks of the basin were smectite, illite, kaolinite, and interlayered illite/smectite. Calcite was the primary cement observed.

Ground-Water Flow System

The ground-water flow system of the study area is quite complex as a result of several sources of recharge, seasonal changes in relations between ground water and the river and irrigation system, faults that juxtapose relatively permeable deposits with impermeable units, and the alteration of hydraulic heads and directions of ground-water flow by sustained ground-water pumping. Depths to water in the study area range from about 5 feet in the inner valley to more than 700 feet on the surrounding piedmont surfaces. Little or no recharge is believed to occur through piedmont surfaces, except at the basin margins and through streambeds during flow. Recharge is known to occur along the Sandia mountain front, although estimates of its quantity vary substantially. Recharge also occurs through the beds of ephemeral streams, such as Tijeras Arroyo. As discussed above, seepage also is known to occur between the Rio Grande and associated irrigation canals and the ground-water system, but the magnitude of the overall contribution of river recharge to ground water is not well constrained. Also uncertain is the quantity of recharge in the vicinity of the Jemez Mountains at the north end of the Middle Rio Grande Basin.

Discharge from the ground-water system includes ground-water pumpage, evapotranspiration in the inner valley, and discharge into drains and gaining reaches of the Rio Grande. Travel times between recharge and discharge areas are dependent in large part on the properties of the aquifer materials present along the flow path. The ground-water model of the Middle Rio Grande Basin constructed by Kernodle and others (1995) used values of hydraulic conductivity ranging between about 0.5 and 70 feet per day in the Albuquerque area to represent the various lithofacies that are present throughout the Santa Fe Group aquifer system.

A map of 1960 hydraulic head by Bjorklund and Maxwell (1961) indicates that ground water in the Albuquerque area flowed primarily from the eastern mountain front beneath the city to the south and west (fig. 4). A map by Bexfield and Anderholm (2000) representing predevelopment (pre-1960) hydraulic heads for the Middle Rio Grande Basin (fig. 5) was compiled using several additional data points. For the Albuquerque area, this map shows similar patterns, except for a somewhat larger component of north-to-south ground-water flow on the east side of the Rio Grande. Both maps show that ground water west of the Rio Grande flows primarily to the southwest. Reasons for the apparent ground-water trough west of Albuquerque are not known. Investigators have theorized that the trough could have a greater thickness of relatively permeable material than surrounding areas (Kernodle and others, 1995), but ground-water modeling results presented by Sanford and others (2001) for the basin indicate that the trough may have developed merely as a result of the low quantity of recharge and its spatial distribution. Another feature of both maps is the presence of large gradients in areas near major faults across which the thickness of permeable sediments varies.

Hydraulic heads for the Santa Fe Group aquifer system in 1992 (fig. 6) differ substantially from pre-1960 heads and indicate substantial changes in the directions of ground-water flow. Compared with pre-1960 water levels, hydraulic heads in 1992 had declined as much as 160 feet along the eastern edge of the study area and as much as 100 feet west of the Rio Grande (Thorn and others, 1993). The largest and most widespread declines have been east of Interstate 25 and particularly near faults along the eastern boundary of the study area. Potentiometric gradients currently are directed from most areas into the pumping centers east and west of the Rio Grande. Such large shifts in ground-water flow directions during the past 30 to 40 years are likely to have local effects on water quality.

Land Use

Data from the U.S. Geological Survey's Geographic Information Retrieval and Analysis System (U.S. Geological Survey, 1983) show that land use in the study area is primarily urban, but that some agricultural land is present in the inner valley and rangeland is present near the western edge. Also within the study area is part of Kirtland Air Force Base in the southeast and bosque and vacant land adjacent to the Rio Grande. Most of the study area is sewered, although homes in some areas, particularly outside the incorporated boundaries of the City of Albuquerque (fig. 1), have individual septic systems. In the inner valley, where depths to water typically are less than about 50 feet, residential, industrial, and agricultural areas exist, all of which are potential sources of contamination to shallow ground water.

METHODS OF STATISTICAL ANALYSIS OF WATER-QUALITY DATA

Knowledge of the statistical methods used to study variability, temporal trends, and correlations in the City of Albuquerque water-quality database is important in understanding the implications of statistical results. For convenience, all statistical methods used in this study are described in this section rather than in the subsequent sections that discuss the results.

General Characteristics of Data Distributions

Characteristics of data distributions often make the use of parametric statistics (statistical methods that assume data are normally distributed) inappropriate. These characteristics include skewness, small sample sizes, and data below detection limits. Distributions of environmental data tend to be positively skewed because negative values are not possible, resulting in a lower bound of zero for all values, with no corresponding upper bound. Calculations of skewness (not shown) for City water-quality data indicate that skewness is common among distributions of most parameters for individual wells. Small sample sizes, which are relatively common for some parameters, do not enable the accurate determination of conformity to a normal distribution. Data below detection limits, which occur relatively frequently for several parameters in the database, also hinder determination of normality and complicate the use of parametric statistics, which require that an actual magnitude be assigned to each data point.

Because parametric statistical methods often are not appropriate for data from the City database, nonparametric methods were used in this study whenever possible. Nonparametric methods do not require an assumption of normality and use ranks of data points relative to each other rather than the actual magnitudes of individual data points. Details of the statistical methods used to investigate various characteristics of the data are given below.

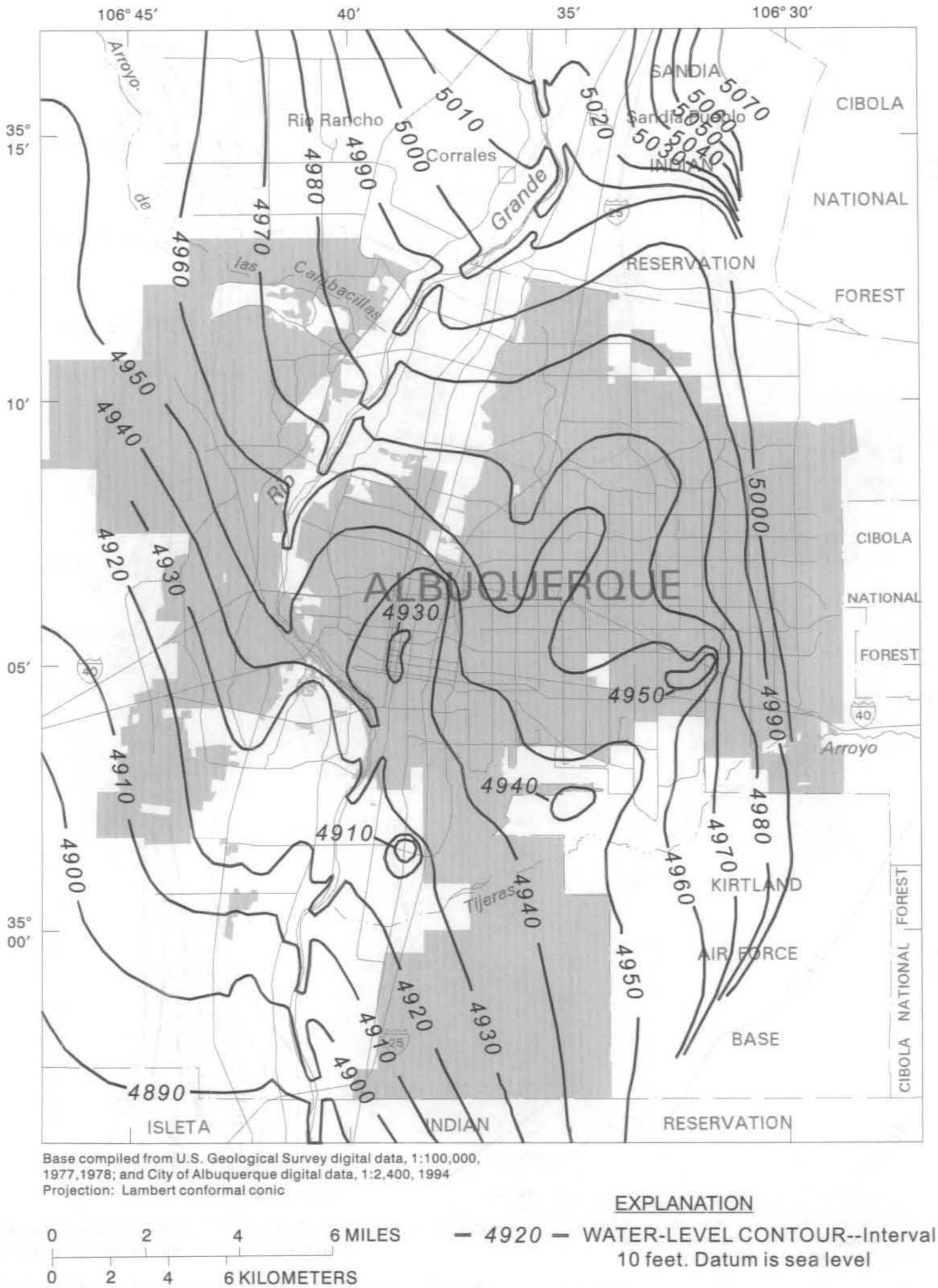


Figure 4. Ground-water levels that represent 1960 conditions in the Santa Fe Group aquifer system in the Albuquerque area (from Thorn and others, 1993, fig. 28, modified from Bjorklund and Maxwell, 1961).

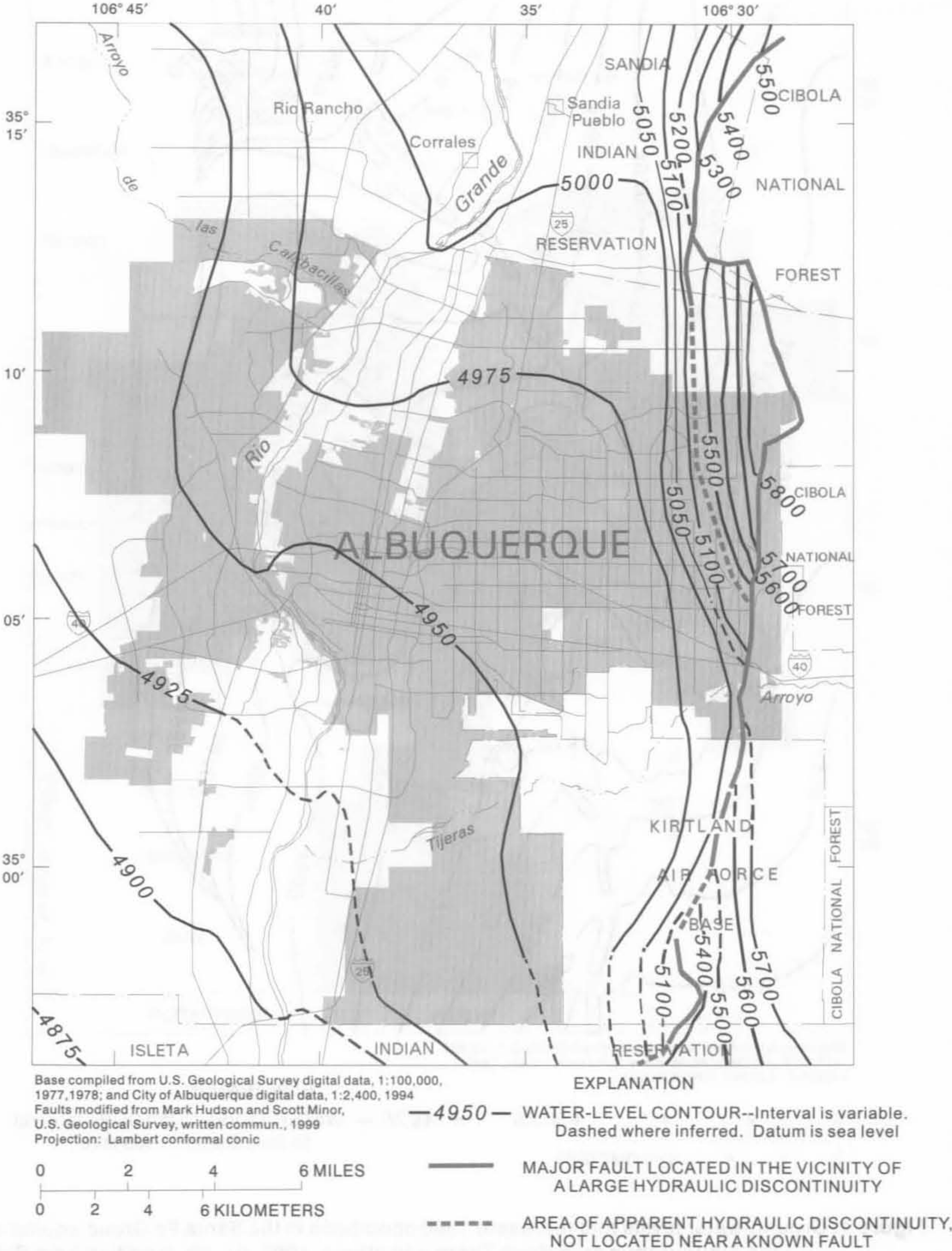
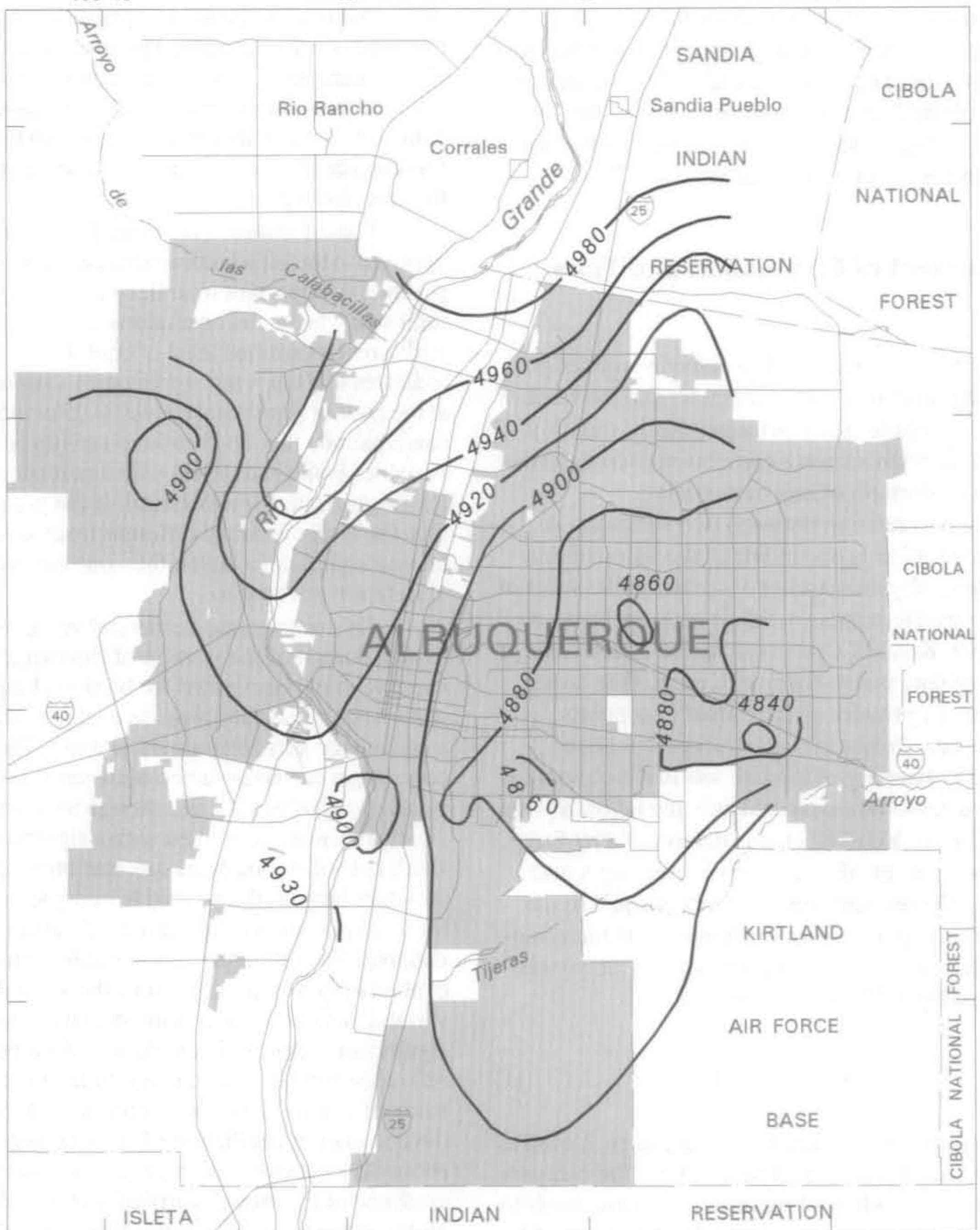


Figure 5. Ground-water levels that represent pre-1960 conditions in the Santa Fe Group aquifer system in the Albuquerque area (modified from Bexfield and Anderholm, 2000).



Base compiled from U.S. Geological Survey digital data, 1:100,000, 1977,1978; and City of Albuquerque digital data, 1:2,400, 1994
Projection: Lambert conformal conic

0 2 4 6 MILES
0 2 4 6 KILOMETERS

EXPLANATION

— *4900* — WATER-LEVEL CONTOUR--Interval is 20 feet. Datum is sea level

Figure 6. Ground-water levels that represent 1992 conditions in the Santa Fe Group aquifer system in the Albuquerque area (modified from Thorn and others, 1993, fig. 30).

Measurement of Variability

To determine the variability of a particular parameter for an individual well, the interquartile range (IQR) was used. The IQR is calculated by subtracting the value of the 25th percentile from that of the 75th percentile and provides a measure of variability that is resistant to the effect of unusual values.

Measurement of Correlation and Time Trends

Kendall's tau was used to detect a correlation between the value of a given parameter and the value of some other variable (such as magnitude of monthly pumpage). Kendall's tau is a correlation coefficient that indicates the strength of any monotonic (unidirectional) relation between two variables. A monotonic relation is one in which the value of one variable generally increases or decreases as the value of the other variable increases, whether this relation is linear or not. Kendall's tau is calculated on the basis of the ranks of data points relative to each other rather than on the magnitudes of individual data points. Therefore, tau is resistant to the effect of unusual values and is meaningful for data sets in which some of the data are censored (measured as being below a given detection limit). Kendall's tau is determined by first ordering all possible data pairs by increasing x and calculating the test statistic, S, which is equal to the number of (x,y) pairs where y increases with increasing x minus the number of (x,y) pairs where y decreases with increasing x. Then, the equation

$$\tau = S / (n(n-1)/2), \qquad (1)$$

where n equals the total number of data pairs, is used to determine tau (Helsel and Hirsch, 1995). Tau can vary between -1 and 1, where -1 represents the case in which y decreases with increasing x for all data pairs and 1 represents the case in which y increases with increasing x for all data pairs. The p-value, or probability of obtaining the calculated value of S when no correlation existed, is then determined by comparing the calculated value of S to the distribution of S that would be expected if there were no correlation. For this study, two-sided hypothesis tests were performed (that is, both positive and negative correlations were identified) and the resulting p-value was compared to a chosen significance level (α) of 0.05. This significance level represents a chance of only 5 percent that a correlation will be assumed where one does not truly exist, which was considered to be an acceptable level of error for this study. If the calculated p-value is less than the significance level, a correlation can be assumed to exist. Although not included in this report, graphs of data were used in this study to confirm the likely presence or absence of each correlation as indicated by the calculated p-value.

The information obtained from Kendall's tau, as opposed to the information obtained from its associated p-value, is important to understand. The p-value indicates whether a correlation can be assumed to exist with a predetermined level of confidence. If the p-value indicates that tau is not significantly different from zero at the chosen significance level (0.05 or other), then one can conclude that no correlation exists between the variables being examined, with a percent confidence of [(1 - significance level) x 100]. If the p-value indicates that tau is significantly different from zero at the chosen significance level, then one can assume that a correlation does exist.

By contrast, the numerical value of tau is a representation of the portion of the variation in the y variable that is accounted for by the relation with the x variable and does not provide evidence about whether a correlation can be assumed to exist. Therefore, a correlation can be assumed between x and y when the p-value is significant, even though the correlation has a small tau value. Combined with a significant p-value, a small tau value simply means that other independent variables besides the x variable being tested are needed for an explanation of all statistical variation in the y variable. Even though the x variable being tested can explain only a small portion of the variation in the y variable, it is nevertheless important to know that x is a significant factor in that variation. As a point of reference for the relative magnitude of tau values, a tau value of about 0.7 or above corresponds to a value of the correlation coefficient r for linear regression of about 0.9 or above, which generally is considered to be evidence of a "strong" correlation (Helsel and Hirsch, 1995). A tau value of this magnitude is really necessary only when the relation between x and y is used to predict the actual value of y for a given x. In this report, the statistical tests used are intended merely to indicate the presence of relations between variables and not to provide equations that can be used for predictions.

When time is the x variable in the determination of Kendall's tau and its associated p-value, the presence or absence of a temporal trend can be determined at the chosen significance level. This nonparametric test, called the Mann-Kendall test, is the trend test used for this study. The Mann-Kendall test is directly analogous to the widely used parametric method of regression over time, in which the test for the significance of the correlation coefficient r is also the significance test for a simple linear regression (Helsel and Hirsch, 1995).

To estimate the magnitude of the trend in the concentration of a particular parameter over a given time period, an estimate of the slope of a fitted line through the data is useful. For this study, the Mann-Kendall test for trend was coupled with the Kendall-Theil robust line, which is a nonparametric line fitted to the data using slopes calculated between data pairs. For a data set of n (x,y) pairs, there are n(n-1)/2 pairwise comparisons and computed slopes (Helsel and Hirsch, 1995). The median of all computed pairwise slopes is taken as the slope of the fitted line, which is made to pass through the (x,y) point consisting of the median of the x values and the median of the y values. By multiplying the slope of this line for a particular parameter by the time period of interest, an estimate of the magnitude of the change in concentration of the parameter over that time period can be obtained. The Kendall-Theil method is less affected by extreme values than the parametric method of linear regression, which estimates an equation relating x and y by minimizing the square of the difference between the predicted y (calculated from the equation) and the observed y at each x.

The power of a trend test to discern changes with time can occasionally be increased by removing variation ("noise") in the y variable due to a particular x variable (x_2) known as an "exogenous" variable (Helsel and Hirsch, 1995). A nonparametric method that adjusts for variation in y due to x_2 involves performing a Mann-Kendall trend test on residuals from a locally weighted scatter plot smoothing (LOWESS) technique of y on x_2. The LOWESS technique develops a smoothed curve of the y against x_2 data using a series of weighted least-squares equations without assuming linearity or normality of residuals (Helsel and Hirsch, 1995). A Mann-Kendall test performed on the residuals from the LOWESS technique has the capability to indicate the presence of a trend in y with time that was hidden by the variation in y due to x_2.

WATER-LEVEL VARIATIONS

Water-level data discussed in this report were collected for piezometer nests throughout the area and therefore represent water levels in different parts of the aquifer (fig. 2). The water level in an individual piezometer represents the hydraulic head in that part of the aquifer where the piezometer is screened. Water levels in the individual piezometers in a piezometer nest are generally not the same, indicating vertical hydraulic-head variation in the aquifer. The vertical variations in water levels result from variations in aquifer properties and variations in recharge to and discharge from the aquifer. Water levels also vary temporally, indicating temporal variations in recharge and discharge. In general, ground water tends to move from areas of higher water levels to areas of lower water levels. In some piezometer nests where water levels in the deeper piezometers are higher than those at the water table, ground water could potentially move upward from deeper parts of the aquifer toward the water table. In piezometer nests where water levels are higher at the water table than in deeper parts of the aquifer, the opposite is true.

Hydraulic conductivity and storage coefficient are two terms used to characterize aquifer properties. Hydraulic conductivity is a measure of the ability of the aquifer to transmit water under hydraulic-head gradients and is a function of the physical properties of the aquifer material and the fluid in the aquifer. In the Albuquerque area, variations in aquifer material locally cause large variations in hydraulic conductivity across small vertical and horizontal distances. Vertical hydraulic conductivity generally is less than horizontal conductivity (Kernodle and others, 1995) in the aquifer; therefore, ground water tends to move more easily horizontally than vertically. The relatively large local variation in aquifer properties and small vertical relative to horizontal hydraulic conductivity in the Albuquerque area cause the deeper parts of the aquifer to be confined or semiconfined, whereas the upper part of the aquifer near the water table is unconfined. In unconfined aquifers, the water table or water level in the aquifer delineates the top of the saturated zone. If water levels decline, water drains from the area that was saturated. In confined aquifers, a decline in hydraulic head does not cause the aquifer to dewater until the hydraulic head declines below the top of the saturated section.

Storage coefficient is a measure of the change in the quantity of water stored in an aquifer when hydraulic head changes. In a confined aquifer, the storage coefficient is determined by the compressibility of the water and the elastic properties of the aquifer material. In an unconfined aquifer, the storage coefficient is determined mainly by the amount of water that drains from the aquifer under the influence of gravity as the water level declines; this amount is related to porosity. The storage coefficient in unconfined aquifers is generally much larger (as much as 10,000 times) than the storage coefficient in confined aquifers. In confined aquifers, water is released quickly when the water level changes. In unconfined aquifers, water is released more slowly because water has to drain from the aquifer as water levels decline.

Ground-water withdrawals from the aquifer by the City for municipal supply have a substantial effect on water levels in the different zones in the aquifer. In general, drinking-water supply wells are screened from the water table or within 275 feet of the water table to the bottom of the well (screened intervals are generally more than 500 feet long) (Bexfield and others, 1999, p. 4). The volume of water withdrawn from any zone in the aquifer by a pumped well is related to the hydraulic head in that zone of the aquifer and the aquifer properties of the zone. In general, more water is withdrawn from the zones of the aquifer with the largest hydraulic conductivities. The total volume of ground water pumped or withdrawn from the aquifer by the City varies seasonally (fig. 7). Withdrawals generally are smaller in December through February and larger in May through July. Withdrawals in the summer are about twice as large as withdrawals in the winter.

Water-Level Variations in Piezometer Nests

The 98th Street piezometer nest is located near the western edge of the study area about one-half mile north of Interstate 40 (fig. 2). The four piezometers are screened at the water table (388 to 433 feet below land surface (BLS)), 739 to 744 feet BLS (mid-shallow), 1,102 to 1,107 feet BLS (mid-deep), and 1,534 to 1,539 feet BLS (deep) (fig. 8).

Water levels at the water table in the 98th Street piezometer nest are about 25 feet higher than in the mid-shallow zone and about 31 feet higher than in the mid-deep and deep zones (fig. 8), indicating downward vertical gradients from the water table to the deeper zones. The downward vertical gradient (equal to the difference in water levels divided by the difference in the bottom of the screened intervals) is about 0.0804 between the water table and the mid-shallow zone and about 0.0165 between the mid-shallow and mid-deep zones. Water levels are generally about 1 foot higher in the deep zone than in the mid-deep zone (fig. 8), indicating an upward gradient of about 0.0023. Seasonal (6-month) variations in water levels at the water table generally are less than 1 foot and do not mimic water-level fluctuations in the deeper piezometers, which are of higher frequency and magnitude (fig. 8). The magnitudes of the seasonal water-level variations are less than 4 feet in the mid-shallow zone and about 6 feet in the mid-deep and deep zones.

In general, water levels in the mid-shallow, mid-deep, and deep zones respond similarly, declining in May through September and rising in October through December (fig. 8). Short-term (weekly) water-level variations in the mid-shallow zone are smoothed relative to the water-level variations in the mid-deep and deep zones. The similarity in the magnitude and timing of water-level variations in the mid-deep and deep zones indicates similar aquifer properties and relatively good hydraulic connection between these zones compared with connection between the other zones.

Water levels in all zones in the 98th Street piezometer nest decreased from the winter of 1997-98 to the winter of 1998-99 (fig. 8), indicating annual (long-term) water-level declines throughout the aquifer. Although variability complicates estimation, water-level declines were greater in the mid-deep and deep zones (about 2 feet) than at the water table (about 1 foot).

The Sierra Vista piezometer nest is located in the northwest part of the study area, about $1^1/_4$ miles west of the Rio Grande and $3^1/_2$ miles north of Interstate 40 (fig. 2). The three piezometers in this nest are screened at the water table (140 to 200 feet BLS), 918 to 923 feet BLS (middle), and 1,634 to 1,639 feet BLS (deep). Water levels at the water table are about 3 feet higher than in the middle zone and about 25 feet higher than in the deep zone (fig. 9), indicating downward vertical gradients between all zones throughout the year. The vertical gradients are about 0.0041 between the water table and middle zone and about 0.0377 between the middle and deep zones. Weekly or monthly water-level variations at the water table and in the deep zone are small (less than 1 foot) compared with water-level variations in the middle zone (more than 1 foot). The differences in the magnitude and timing of water-level variations between the middle and deep zones indicate poor hydraulic connection between these zones.

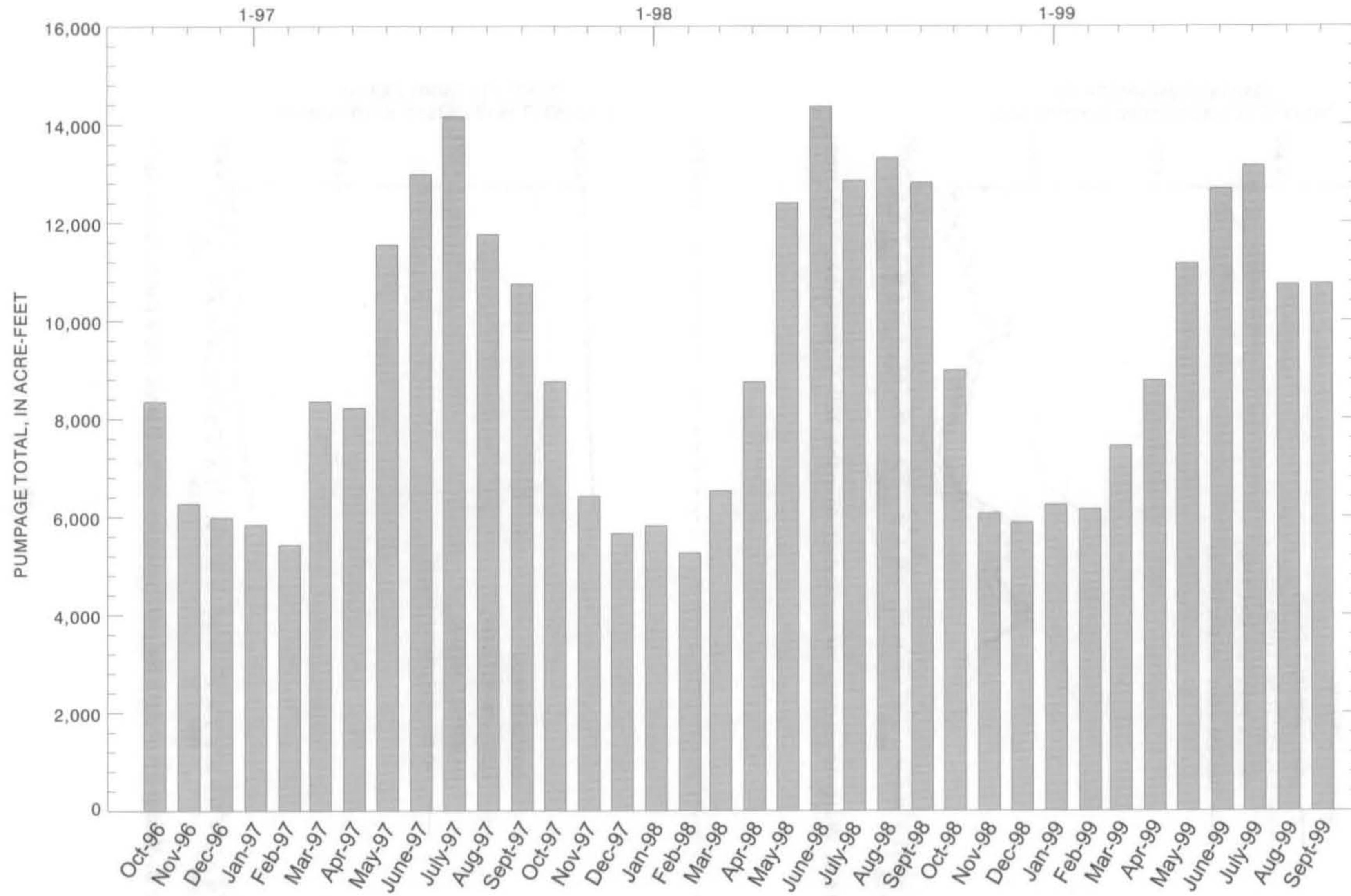


Figure 7. Monthly pumpage totals for all City of Albuquerque drinking-water supply wells, October 1996 through September 1999.

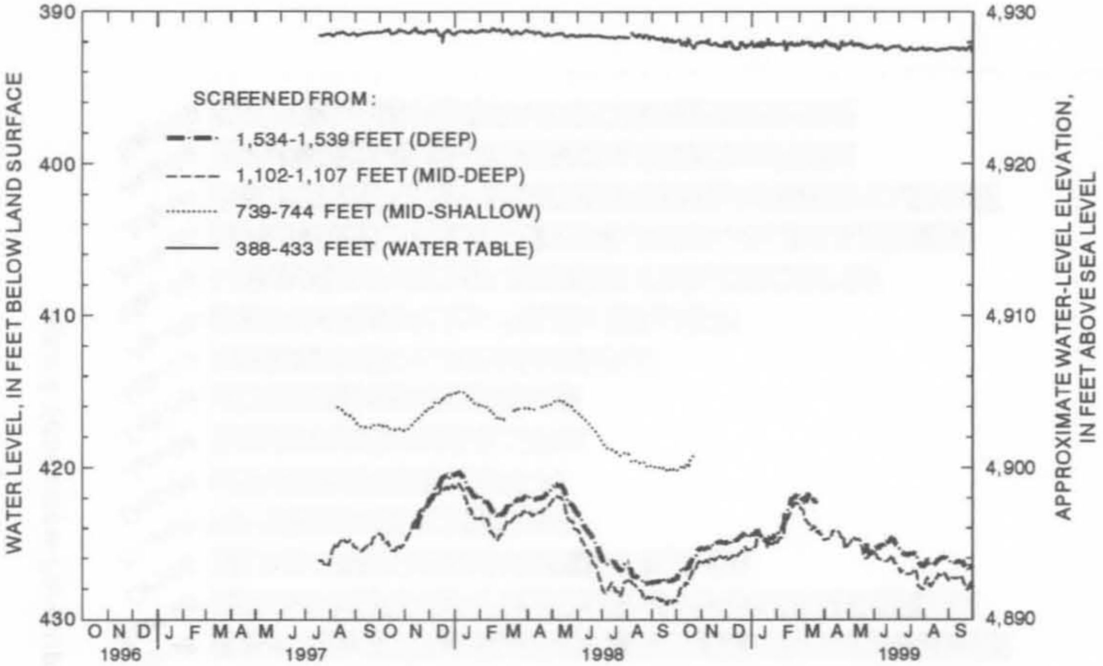


Figure 8. Water-level data for piezometers in the 98th Street piezometer nest.

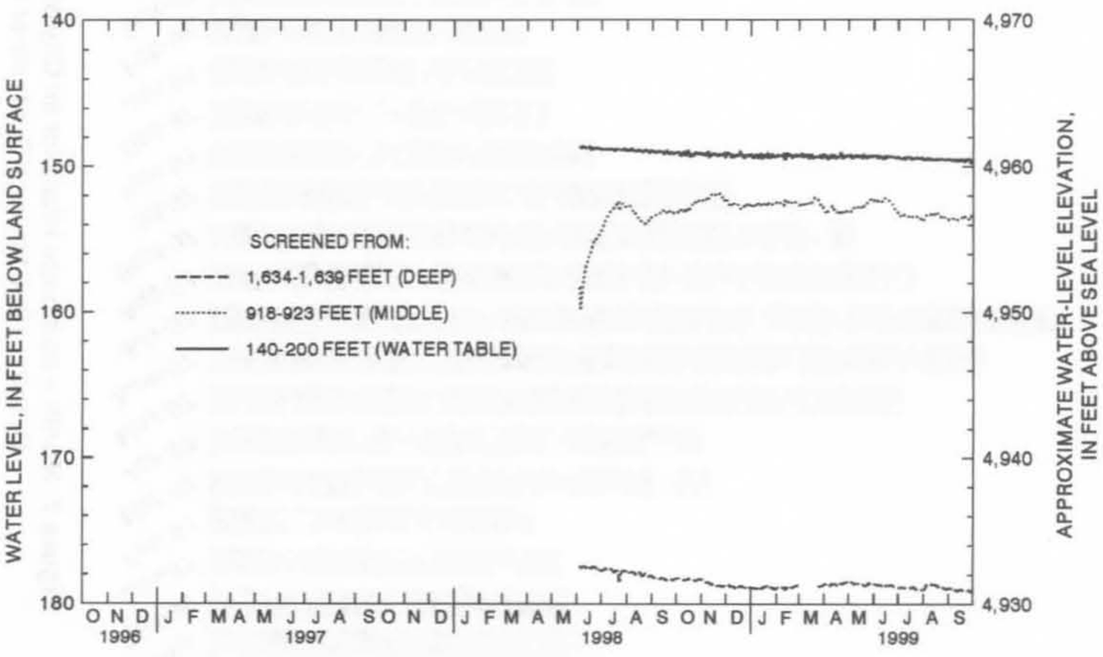


Figure 9. Water-level data for piezometers in the Sierra Vista piezometer nest.

Water levels at the water table and in the deep zone declined about 0.75 and 1.25 feet, respectively, from June 1998 to June 1999 (fig. 9). There is no clear trend in water levels in the middle zone.

The West Bluff piezometer nest is located about 500 feet west of the Rio Grande and about one-fourth mile north of Interstate 40 (fig. 2). Because this nest is within 1,000 feet of the Gonzales 2 drinking-water supply well, its water levels are affected by pumpage from an individual supply well much more than water levels in the other piezometer nests are. Two wells were drilled at this site, and three piezometers were installed in each well. Water levels in piezometers screened at the water table (143 to 163 feet BLS) in one well and at 422 to 427 feet BLS (mid-shallow), 679 to 684 feet BLS (mid-deep), and 1,085 to 1,090 feet BLS (deep) in the other well are discussed. Water levels in piezometers screened at the 244- to 249-foot zone and the 318- to 323-foot zone in one well differ only minimally from water levels in the mid-shallow zone; consequently, they are not discussed.

Although seasonal variations alter the relations between water levels in the various zones in the West Bluff piezometer nest, water levels generally indicate downward gradients between all adjacent zones (fig. 10). Downward vertical gradients are generally largest in the summer between the water table and mid-shallow zones (0.0188) and the mid-shallow and mid-deep (0.0416) zones. They are largest in the winter between the mid-deep and deep zones (0.0172).

The magnitude and timing of seasonal water-level variations in the West Bluff piezometers differ. The seasonal water-level variations at the water table generally are less than 2 feet and generally do not mimic water levels in the other piezometers (fig. 10). Water levels at the water table rise from April/May until June/July, probably in response to increased recharge from the Rio Grande resulting from higher river stage. Water levels decline after June/July probably in response to increases in ground-water withdrawals (as demonstrated by water-level declines in the other zones). Short-term (weekly) variations generally are greater in the mid-deep zone than in the other zones, possibly indicating that most withdrawals from the adjacent supply well, which is screened from 400 to 1,100 feet BLS, are from this zone. Seasonal water-level variations in 1998 were greater than 20 feet in the mid-deep zone, about 15 feet in the deep zone, and less than 6 feet in the mid-shallow zone. Water-level variations in the deep zone are smoothed relative to the mid-deep and mid-shallow zones, possibly indicating a better hydraulic connection between the mid-shallow and mid-deep zones than between the mid-deep and deep zones or a small contribution of water from the deep zone to the total water pumped from Gonzales 2. Over about a 3-year period (early 1997 to September 1999), water levels appeared to decline in all zones (fig. 10).

The Garfield Park piezometer nest is about $2^1/_2$ miles east of the Rio Grande and about 1 mile north of Interstate 40 (fig. 2). Its three piezometers are screened at the water table (43 to 83 feet BLS), 552 to 572 feet BLS (middle), and 995 to 1,010 feet BLS (deep). Water levels indicate downward vertical gradients between adjacent zones. The difference in water levels between the water table and the middle zone varies seasonally from less than 1 foot to about 10 feet (fig. 11), indicating that downward vertical gradients vary from a very slight gradient in the winter to 0.0204 in the summer. Water-level differences between the middle and deep zones generally are less than 1 foot and are largest in the summer. Water levels in the middle and deep zones decline from about March until July and rise from about September until December probably in response to seasonal changes in withdrawals from municipal wells in the area. Annual water-level variations in the middle and deep zones are about 8-10 feet. Water-level changes in the middle and deep zones are similar and show no discernible lag between these zones, indicating relatively good hydraulic connection between them.

Water levels at the water table have a distinct annual pattern, rising about 1 to 2 feet in March through about June/July and declining thereafter (fig. 11). The rapid rise in water levels at the water table in March corresponds with the diversion of water from the Rio Grande into the irrigation system, which implies relatively rapid recharge to the aquifer as the result of infiltration of water from the irrigation system. Water levels decline at the water table from about July until March in response to downward leakage of water to deeper zones and diminished recharge when river water is not being diverted into the irrigation system (October until March). The rise in water levels in the middle and deep zones, while water levels decline at the water table, could indicate relatively good hydraulic connection between all zones in this area.

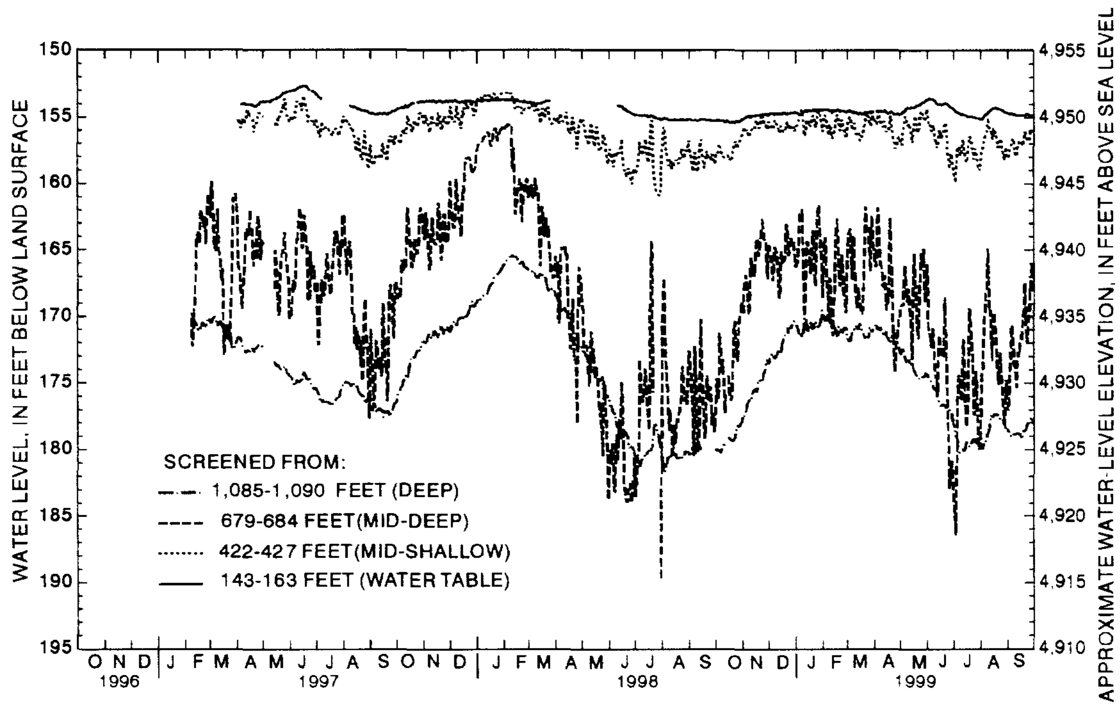


Figure 10. Water-level data for piezometers in the West Bluff piezometer nest.

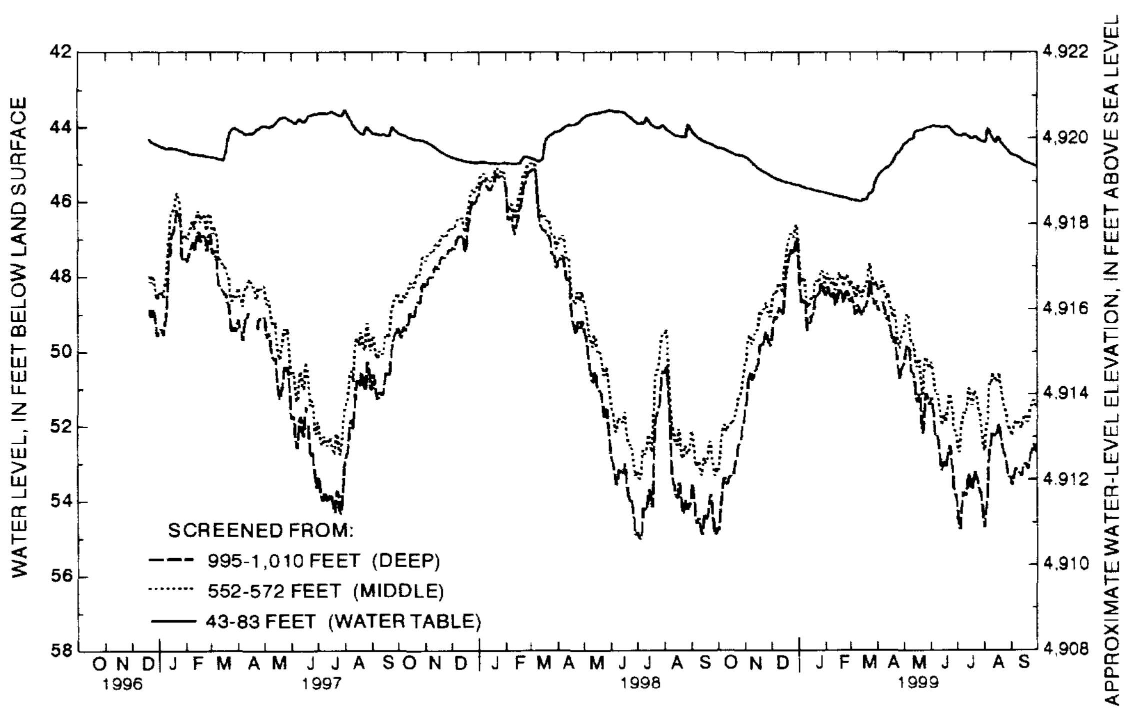


Figure 11. Water-level data for piezometers in the Garfield Park piezometer nest.

It is difficult to determine any annual (long-term) trends in water levels at the Garfield Park piezometer nest. Water levels at the water table seem to be decreasing (less than 1 foot from June 1997 to June 1999) (fig. 11), but any long-term water-level trends in the other two zones are unknown.

The Del Sol Divider piezometer nest is about one-half mile south of Interstate 40 and $2^1/_4$ miles east of Interstate 25 (fig. 2). The three piezometers at this site are screened at the water table (315 to 415 feet BLS), 832 to 837 feet BLS (middle), and 1,557 to 1,562 feet BLS (deep). Water levels at the water table are lower than those in the middle zone from about October until March and always lower than water levels in the deep zone (fig. 12), indicating upward vertical gradients between deeper zones and the water table most of the year. Water levels are consistently about 8 to 10 feet higher in the deep zone than in the middle zone, indicating upward vertical gradients of about 0.0124 between these zones. Water levels at the water table vary about 2 feet seasonally, with higher water levels from about February through May. Water levels vary about 15 feet seasonally in the middle and deep zones, with higher water levels in December through February and lower water levels in June and July (fig. 12).

Although there are differences in the magnitude and timing of seasonal water-level variations in the Del Sol Divider piezometer nest, water levels in all zones generally decrease in the summer and increase in the winter, indicating some connection between all zones. Short-term water-level variations in the deep zone are generally smoothed relative to the middle zone (fig. 12), indicating that most ground-water withdrawals in the area probably are from the middle zone. Annually, water levels are generally declining in all piezometers at a rate of about 1 to 1.5 feet per year, with the smallest rate at the water table and the largest rate in the deep zone.

The Nor Este piezometer nest is located in the northern part of the study area about $1^1/_2$ miles east of Interstate 40 (fig. 2). The three piezometers at this site are screened at the water table (538 to 598 feet BLS), 1,183 to 1,188 feet BLS (middle), and 1,515 to 1,520 feet BLS (deep). Water levels at the water table generally are lower than those in the other two zones (fig. 13), indicating upward vertical gradients. However, water levels in the middle zone are occasionally lower than those at the water table, primarily in May through July. Water levels in the middle zone are about 2 feet lower than those in the deep zone, indicating upward vertical gradients of about 0.006 between these two zones. Water-level variations in the deep zone are smaller and are smoothed relative to water levels in the middle zone, indicating that most ground-water withdrawals in the area probably are from the middle zone. The seasonal water-level variation at the water table is about 2 feet and in the middle and deep zones is about 3 feet. Water levels in all zones respond similarly, indicating good hydraulic connection between the different zones. Although data are limited, water-level declines are about 1 to 2 feet per year in all zones.

The Sister Cities piezometer nest is located in the northeastern part of the study area about one-half mile east of Interstate 25 (fig. 2). Piezometers are screened from 789 to 794 feet BLS (middle) and from 1,298 to 1,303 feet BLS (deep) zones at this site. Water levels generally are lower in the deep zone than in the middle zone from about April through October, indicating downward vertical gradients, and about the same or slightly higher in the deep zone than the middle zone from November through March, indicating small upward vertical gradients (fig. 14). The magnitude of seasonal water-level variations is about 10 feet in the deep zone and about 5 feet in the middle zone. Water-level variations in the deep zone slightly lag behind those in the middle zone, indicating that most ground-water withdrawals are from the middle zone and that hydraulic connection is relatively poor between zones. The larger seasonal water-level variations in the deep zone relative to the middle zone could indicate differences in hydraulic properties in the different zones. Water levels in both zones declined about 1 foot from January 1998 to January 1999.

The Matheson Park piezometer nest is located in the eastern part of the study area about $2^1/_2$ miles north of Interstate 40 (fig. 2). The three piezometers at this site are screened at the water table (600 to 700 feet BLS), 1,020 to 1,040 feet BLS (middle), and 1,460 to 1,500 feet BLS (deep). Water levels at the water table are about 140 feet higher than those in the middle and deep zones (fig. 15), indicating either large downward gradients or a perched zone of water above the regional water table. For the $1^1/_2$ years of record, water levels in the deep zone were higher than those in the middle zone from November through March and lower from April through October. Water levels in both the middle and deep zones decline from April until June/July and rise from about September/October until January, probably in response to changes in ground-water

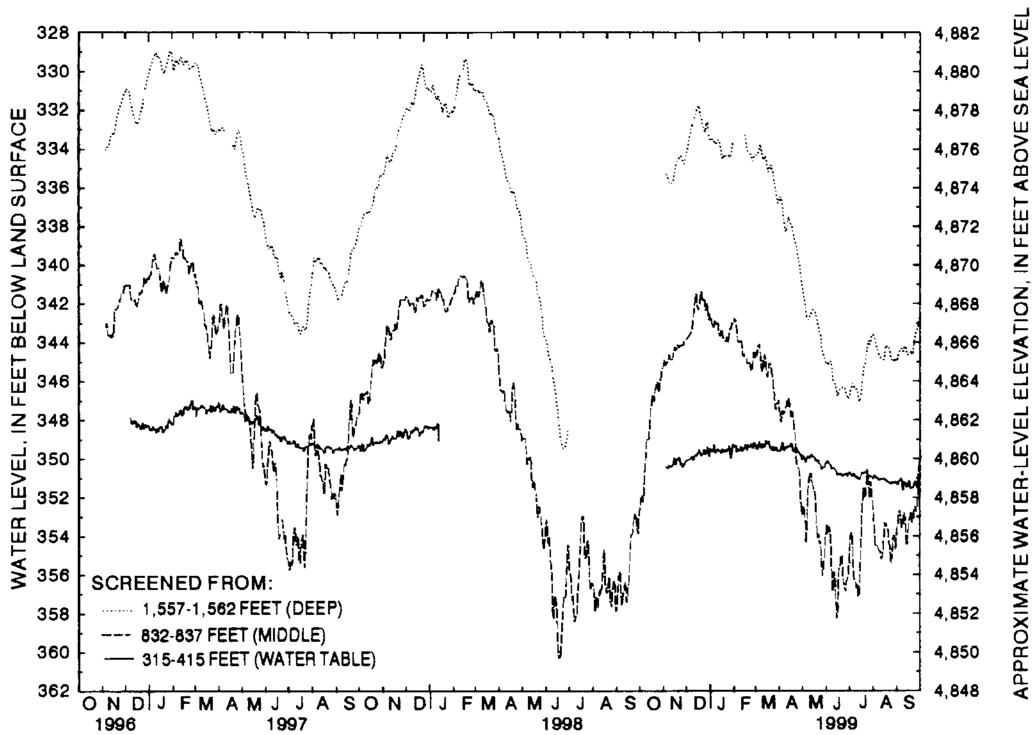


Figure 12. Water-level data for piezometers in the Del Sol Divider piezometer nest.

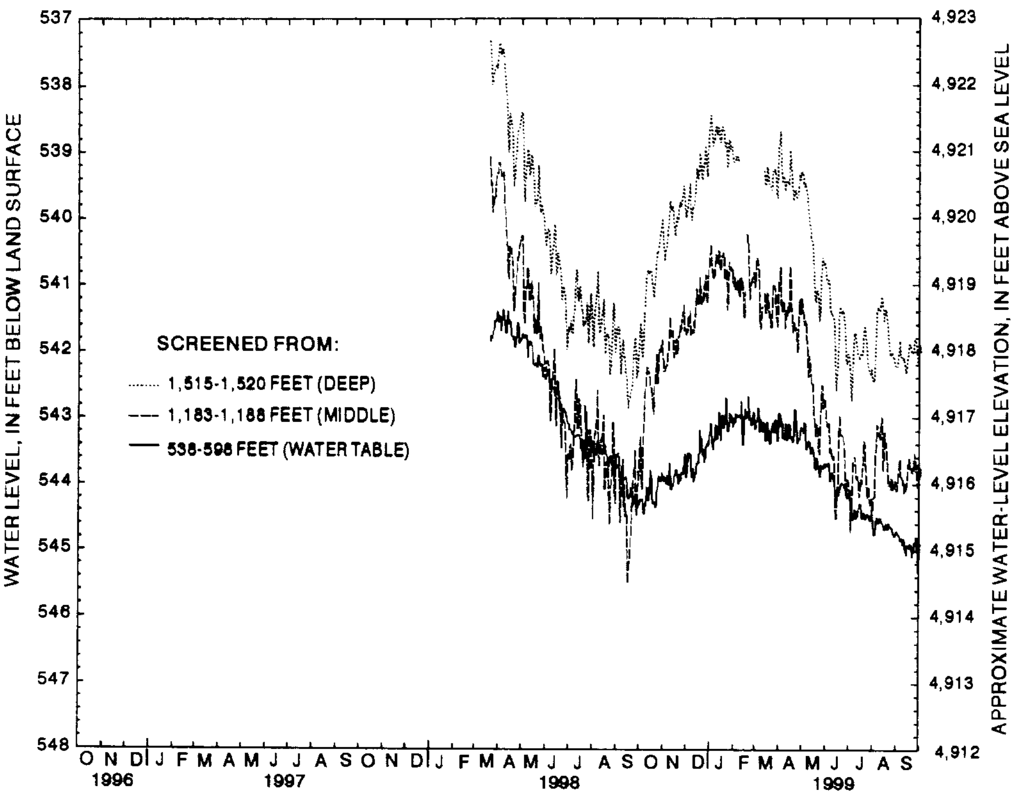


Figure 13. Water-level data for piezometers in the Nor Este piezometer nest.

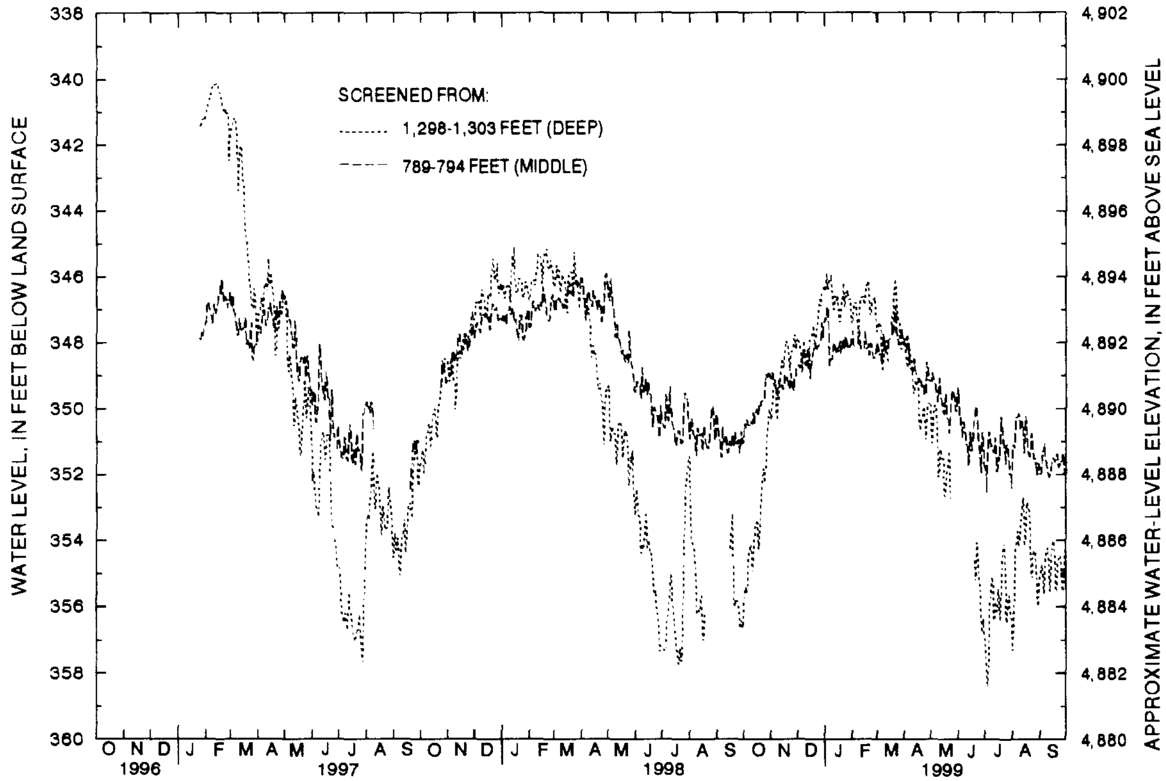


Figure 14. Water-level data for piezometers in the Sister Cities piezometer nest.

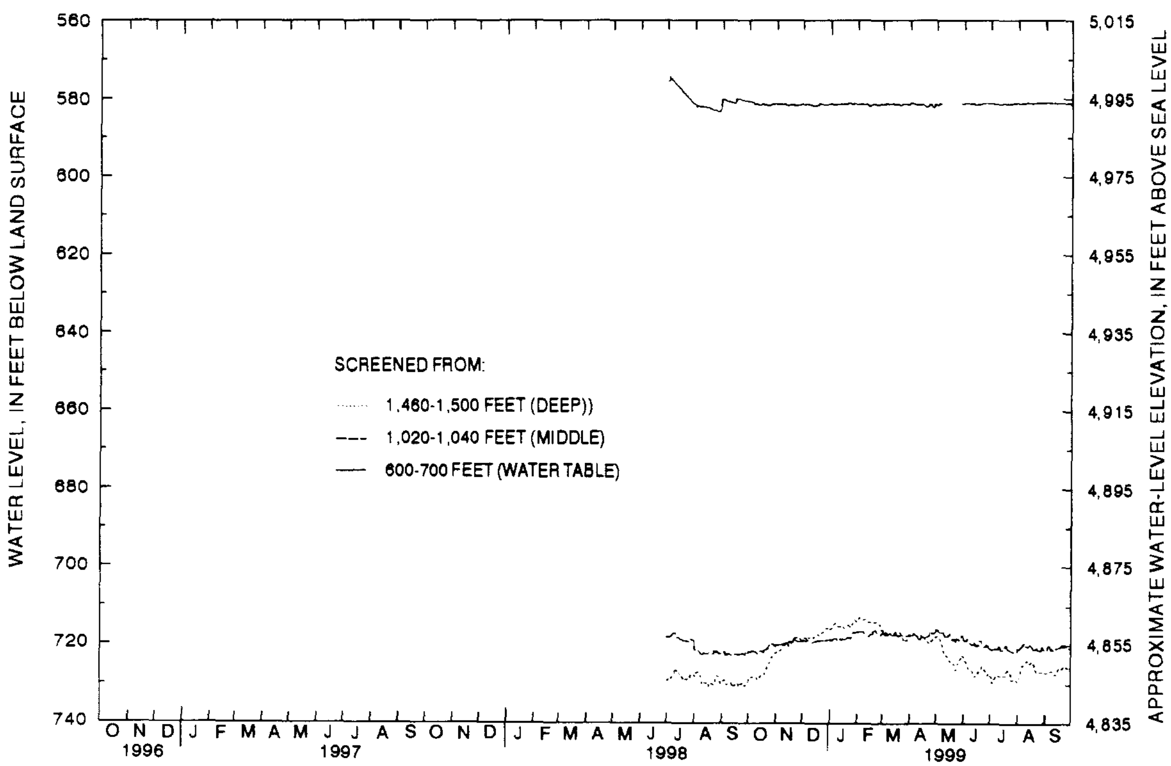


Figure 15. Water-level data for piezometers in the Matheson Park piezometer nest.

withdrawals. Water levels at the water table do not seem to be related to those in the deeper zones, indicating little or no hydraulic connection between the water table and deeper zones. The seasonal variations in water levels are larger in the deep zone (about 17 feet) than in the middle zone (about 6 feet). Based on about 1 year of water-level measurements, the water levels in all zones are increasing slightly.

Summary of Water-Level Variations in Piezometer Nests

Knowledge of similarities and differences in vertical gradients, magnitude and timing of seasonal water-level variations, and long-term (annual) water-level trends in many of the piezometer nests can be useful in better understanding the aquifer on a regional scale. In particular, water levels in the piezometer nests provide information about vertical and horizontal variations in hydraulic properties and the way in which the aquifer responds seasonally and annually to variations in recharge and discharge from different parts of the aquifer.

In general, vertical hydraulic gradients are downward west of Interstate 25 and upward east of Interstate 25. With the exception of the Matheson Park site, vertical gradients generally are larger west of Interstate 25 than east of Interstate 25, indicating smaller vertical hydraulic conductivities on the western side of the city than those on the east side. Downward gradients west of Interstate 25 indicate that recharge from the Rio Grande or ground water from the shallow part of the aquifer tends to move downward from upper to lower zones in the aquifer. The downward vertical gradients are probably due to the effects of municipal ground-water withdrawals from deeper parts of the aquifer. The downward gradients are consistent with a conceptual model of recharge from the Rio Grande and movement of ground water southwestward. On the east side of Interstate 25, water levels indicate that ground water tends to move upward from the deeper zones toward the water table. These upward gradients could be due to ground-water withdrawals from the upper part of the aquifer.

Large water-level declines east of Interstate 25 have probably had an important effect on vertical gradients in the area. On the basis of computer simulations of ground-water flow (Kernodle and others, 1995, p. 64-65), water levels have declined about 100 feet in the area of the Del Sol Divider piezometer nest and about 80 feet in the area of the Sister Cities piezometer nest since predevelopment conditions. Declines in water levels in the upper and middle parts of the aquifer where most of the withdrawals have occurred could have reversed vertical gradients or increased pre-existing upward gradients and the potential for movement of ground water from deeper parts of the aquifer.

Water-level variations at the water table generally are smaller than those in deep zones in all the piezometers. Variations are expected to be smaller at the water table than in deeper parts of the aquifer because of the difference in storage coefficient in unconfined (water table) and confined aquifers (deeper zones). Water levels at the water table where conditions are unconfined respond to withdrawals more slowly than water levels deeper in the aquifer because of the time necessary for water to drain from the aquifer.

In general, water levels measured in the zones below the water table in all piezometers respond to seasonal variations in ground-water withdrawals. From about April until June/July water levels generally decline and from about September until January they rise. Total ground-water withdrawals for City municipal wells in the summer are about twice the winter total because water is used for evaporative coolers and lawn irrigation. This seasonal difference is manifested in regional water levels throughout the area.

The magnitudes of seasonal water-level variations often vary with depth at a particular nest and between nests. This variation is probably due to areal differences in the volume of ground-water withdrawals, differences in screened intervals of supply wells, proximity of the piezometer nests to municipal supply wells, and regional differences in aquifer properties. Some of the largest seasonal water-level variations in both the middle and deep zones are in the Del Sol Divider, Matheson Park, and West Bluff piezometer nests. The Del Sol Divider and Matheson Park sites are located in the areas of largest water-level declines (Kernodle and others, 1995), possibly indicating larger ground-water withdrawals and little recharge. Water-level declines are smaller near the Rio Grande because of recharge from the Rio Grande and irrigation system in this area. The West Bluff site is closer to a municipal supply well than any of the other piezometer nests (within 1,000 feet of the Gonzales 2 drinking-water supply well) and likely is strongly affected by withdrawals from this well. The smallest seasonal variations are in the Sierra Vista and Nor Este piezometer nests. These nests are in less developed or recently developed parts of Albuquerque (farther from municipal supply wells) and likely are less affected by local ground-water withdrawals.

Although difficult to quantify because of large seasonal variations, water levels appear to be declining annually in most of the piezometers. Water-level declines are generally less than 1 foot per year. These declines indicate that the volume of inflow to the aquifer is less than the volume of outflow from the aquifer.

Water levels do not seem to be declining in the Garfield Park and Matheson Park piezometer nests. The lack of declines in the Garfield Park piezometer nest, especially at the water table, probably indicates that the volume of ground-water inflow (recharge) in this area approximates the volume of ground-water outflow. Water levels in all zones in the Matheson Park piezometer nest seem to have risen slightly over the period of record. Water levels in the middle and deep zones clearly respond to seasonal ground-water withdrawals in the area, although the withdrawals do not seem to cause water-level declines in this area. The reason for this is unclear. Water levels at the water table do not seem to respond to seasonal ground-water withdrawals, possibly indicating little or no hydraulic connection between the upper part and deeper parts of the aquifer.

SPATIAL PATTERNS IN WATER QUALITY

Knowledge of patterns in the distribution of chemical concentrations and physical properties both areally and with depth in an aquifer can aid in drawing conclusions about the geohydrologic framework. In a preceding report (Bexfield and others, 1999), median values of chemical concentrations and physical properties were tabulated for City drinking-water supply wells. Median values were used in that report to determine water types and to make maps that showed the relative magnitudes of the parameter values among the drinking-water supply wells. For this report, the distributions of water types and water-quality parameters for various wells have been studied to provide information about the geohydrologic framework.

Under most conditions, ground-water chemistry near a recharge area reflects primarily the general chemistry of the recharge water and lithology of the recharge area. As water moves down a flow path, its chemistry will evolve as the result of interaction with aquifer materials and (or) mixing with water from other recharge sources. Therefore, spatial patterns in the distribution of water quality are useful for determining recharge areas, chemical reactions along flow paths, and areas of mixing. These patterns also can be used to validate conceptual models of ground-water flow based on hydraulic-head distributions. Because the ground-water flow system has been altered by the pumpage of large volumes of water over a short time period (about the last 40 years) compared to the amount of time necessary for ground water to move large distances, the major, regional water-quality patterns discussed in this report are believed to be representative of those that were present before large ground-water withdrawals began. However, changes in the distribution of hydraulic heads may have had localized effects on the distribution of water quality. The following discussion is organized on the basis of areal and vertical water-chemistry variations.

Areal Patterns in Water Quality

Several water-quality parameters were plotted and contoured to represent water quality in the main zone of pumping for City drinking-water supply wells (see table 2 for screened intervals). These plots include median values for the drinking-water supply wells. The use of median values to investigate areal patterns is believed to be appropriate because, as discussed in subsequent sections, temporal trends in water quality for an individual well typically are small, particularly in relation to the contour intervals chosen for this investigation. Therefore, although variability in a parameter among the wells for different sampling times could result in small changes in contour locations, it would not change regional water-quality patterns. Also, use of median values is believed to be preferable to the use of individual sample values because any effects from random laboratory error are essentially avoided. To include as much water-quality information as possible in areas without drinking-water supply wells, plots of parameters also include the data available for individual samples for the piezometer nests discussed earlier (data generally were not available for more than one sampling event at an individual nest). Only those data for piezometer completions within the production zone of City drinking-water supply wells (generally the middle-piezometer completion) were used.

Table 2. Selected completion data for City of Albuquerque drinking-water supply wells
[ft, feet; asl, above sea level; bls, below land surface; nd, no data]

Well name	Land-surface elevation (ft asl)	Depth to top of screened interval (ft bls)	Depth to bottom of screened interval (ft bls)	Elevation of top of screened interval (ft asl)	Elevation of bottom of screened interval (ft asl)	Elevation of midpoint of screened interval (ft asl)
Atrisco 1	4,945	280	1,283	4,665	3,662	4,164
Atrisco 2	4,945	108	250	4,837	4,695	4,766
Atrisco 3	4,950	180	804	4,770	4,146	4,458
Atrisco 4	4,950	98	475	4,852	4,475	4,664
Burton 1	5,315	676	1,292	4,639	4,023	4,331
Burton 2	5,284	425	845	4,859	4,439	4,649
Burton 3	5,215	358	994	4,857	4,221	4,539
Burton 4	5,275	636	1,276	4,639	3,999	4,319
Burton 5	5,276	550	1,170	4,726	4,106	4,416
Charles Wells 1	5,315	456	1,032	4,859	4,283	4,571
Charles Wells 2	5,262	432	996	4,830	4,266	4,548
Charles Wells 3	5,275	420	996	4,855	4,279	4,567
Charles Wells 4	5,324	456	1,032	4,868	4,292	4,580
Charles Wells 5	5,222	625	1,385	4,597	3,837	4,217
College 1	5,336	660	1,650	4,676	3,686	4,181
College 2	5,228	550	1,564	4,678	3,664	4,171
Coronado 1	5,289	479	1,184	4,810	4,105	4,458
Coronado 2	5,242	590	1,390	4,652	3,852	4,252
Duranes 1	4,960	204	924	4,756	4,036	4,396
Duranes 2	4,970	180	804	4,790	4,166	4,478
Duranes 3	4,962	132	950	4,830	4,012	4,421
Duranes 4	4,960	144	950	4,816	4,010	4,413
Duranes 5	4,960	152	950	4,808	4,010	4,409
Duranes 6	4,962	260	500	4,702	4,462	4,582
Duranes 7	4,962	144	814	4,818	4,148	4,483
Gonzales 1	5,111	350	950	4,761	4,161	4,461
Gonzales 2	5,100	400	1,100	4,700	4,000	4,350
Griegos 1	4,972	232	802	4,740	4,170	4,455
Griegos 2	4,965	164	820	4,801	4,145	4,473
Griegos 3	4,968	260	916	4,708	4,052	4,380
Griegos 4	4,975	218	804	4,757	4,171	4,464
Leavitt 1	5,083	317	1,217	4,766	3,866	4,316
Leavitt 2	5,073	281	1,121	4,792	3,952	4,372
Leavitt 3	5,080	514	1,500	4,566	3,580	4,073
Lomas 1	5,595	700	1,300	4,895	4,295	4,595
Lomas 5	5,494	830	1,658	4,664	3,836	4,250
Lomas 6	5,529	880	1,692	4,649	3,837	4,243
Love 1	5,465	596	1,096	4,869	4,369	4,619
Love 3	5,405	600	1,260	4,805	4,145	4,475
Love 4	5,370	600	1,284	4,770	4,086	4,428
Love 5	5,390	660	1,248	4,730	4,142	4,436
Love 6	5,505	753	1,509	4,752	3,996	4,374
Love 7	5,440	645	1,473	4,795	3,967	4,381
Love 8	5,316	640	1,440	4,676	3,876	4,276
Leyendecker 1	5,285	468	996	4,817	4,289	4,553
Leyendecker 2	5,298	468	996	4,830	4,302	4,566
Leyendecker 3	5,265	456	996	4,809	4,269	4,539
Leyendecker 4	5,325	480	996	4,845	4,329	4,587
Miles Road 1	5,154	404	1,153	4,750	4,001	4,376
Ponderosa 1	5,649	964	1,693	4,685	3,956	4,321

Table 2. Selected completion data for City of Albuquerque drinking-water supply wells--Concluded

Well name	Land-surface elevation (ft asl)	Depth to top of screened interval (ft bls)	Depth to bottom of screened interval (ft bls)	Elevation of top of screened interval (ft asl)	Elevation of bottom of screened interval (ft asl)	Elevation of midpoint of screened interval (ft asl)
Ponderosa 2	5,600	801	1,569	4,799	4,031	4,415
Ponderosa 3	5,527	870	1,590	4,657	3,937	4,297
Ponderosa 4	5,629	936	1,738	4,693	3,891	4,292
Ponderosa 5	5,630	939	1,613	4,691	4,017	4,354
Ponderosa 6	5,558	852	1,662	4,706	3,896	4,301
Ridgecrest 1	5,442	636	1,260	4,806	4,182	4,494
Ridgecrest 2	5,416	730	1,500	4,686	3,916	4,301
Ridgecrest 3	5,385	620	1,436	4,765	3,949	4,357
Ridgecrest 4	5,344	572	1,412	4,772	3,932	4,352
Ridgecrest 5	5,355	636	1,260	4,719	4,095	4,407
Santa Barbara 1	5,139	312	984	4,827	4,155	4,491
San Jose 1	4,950	nd	nd	nd	nd	nd
San Jose 2	4,997	264	996	4,733	4,001	4,367
San Jose 3	4,952	192	1,032	4,760	3,920	4,340
Thomas 1	5,445	624	1,092	4,821	4,353	4,587
Thomas 2	5,490	696	1,224	4,794	4,266	4,530
Thomas 3	5,415	672	1,200	4,743	4,215	4,479
Thomas 4	5,485	672	1,020	4,813	4,465	4,639
Thomas 5	5,356	722	1,450	4,634	3,906	4,270
Thomas 6	5,412	760	1,520	4,652	3,892	4,272
Thomas 7	5,347	659	1,460	4,688	3,887	4,288
Thomas 8	5,462	835	1,635	4,627	3,827	4,227
Vol Andia 1	5,144	300	972	4,844	4,172	4,508
Vol Andia 2	5,208	360	852	4,848	4,356	4,602
Vol Andia 3	5,110	264	900	4,846	4,210	4,528
Vol Andia 4	5,200	372	876	4,828	4,324	4,576
Vol Andia 5	5,112	260	900	4,852	4,212	4,532
Vol Andia 6	5,178	324	984	4,854	4,194	4,524
Volcano Cliffs 1	5,335	528	1,056	4,807	4,279	4,543
Volcano Cliffs 2	5,328	528	876	4,800	4,452	4,626
Volcano Cliffs 3	5,345	659	1,302	4,686	4,043	4,365
Webster 1	5,436	620	1,345	4,816	4,091	4,454
Webster 2	5,387	608	1,334	4,779	4,053	4,416
Walker 1	5,698	982	1,703	4,716	3,995	4,356
Walker 2	5,596	852	1,773	4,744	3,823	4,284
West Mesa 1	5,175	504	1,176	4,671	3,999	4,335
West Mesa 2	5,165	394	1,402	4,771	3,763	4,267
West Mesa 3	5,145	405	1,353	4,740	3,792	4,266
West Mesa 4	5,105	387	1,275	4,718	3,830	4,274
Yale 1	5,159	336	960	4,823	4,199	4,511
Yale 2	5,128	351	1,179	4,777	3,949	4,363
Yale 3	5,080	320	992	4,760	4,088	4,424
Zamora 1	5,168	450	950	4,718	4,218	4,468

Within the production zone, water-quality variations with increasing depth at an individual location were assumed to be relatively small. This assumption will later be seen to be tenuous for certain parts of the study area. Nevertheless, the available data show quite distinct areal patterns in water quality, despite many of these data coming from wells with large screened intervals of varying depths below land surface. Probably because most of the data represent mixed waters from large depth intervals, most but not all data points fit the contours for every parameter. Although the areal patterns obtained are believed to accurately represent the quality of water in the production zone of City drinking-water supply wells, they may not represent the quality of water in either very shallow or very deep zones of the aquifer.

The study area was divided into the five regions of similar water quality shown in figure 16 on the basis of plots of chemical parameters (figs. 17 through 29). These regions are similar to, but not coincident with, the five study area divisions of Logan (1990). The divisions used by Logan were based on assumptions about ground-water sources and flow directions, in addition to patterns in chemical parameters. The water-quality regions defined in this study are based entirely on chemical considerations, although they are named for their geographic locations (fig. 16). The boundaries between these zones of similar water quality are meant to show the approximate areas of transition between waters of different chemical characteristics and probably are not as sharply delineated as in figure 16. Also, these boundaries undoubtedly shift somewhat in location with depth. In addition to facilitating discussion of areal patterns in water quality, these region definitions enable inferences to be drawn about possible ground-water sources and flow paths based primarily on water quality. These inferences can then be compared to conclusions drawn from other hydrologic parameters (such as hydraulic head). Also, defining regions that are based solely on water quality can aid in examining why large variations in certain water-quality parameters are measured with time in some individual wells but not in others. In particular, proximity to a transitional boundary between zones of substantially different water quality can help to explain such variations. This section summarizes the water-quality characteristics of the zones defined in figure 16 and provides possible reasons for the differences in water quality observed between zones.

Chemical Characteristics of the Water-Quality Regions

The Mountain Front region was defined on the basis of several chemical parameters, including specific conductance (a measure of the ability of a water sample to conduct electricity that generally increases as dissolved-solids concentration increases), sodium, silica, and arsenic (figs. 17, 22, 23, and 25). Ground water in this region typically has small concentrations of these parameters compared with most or all other regions (table 3). According to the water-type designations on the Piper diagram in figure 27, which shows the relative equivalent proportions of the major ions found in water from each City drinking-water supply well, most wells in the Mountain Front region produce water of the calcium/carbonate + bicarbonate type (fig. 28). However, a few wells (Lomas 5 and 6 and Love 1 and 6) produce water of the sodium + potassium or mixed cation type; these wells appear to be screened at different intervals than surrounding wells and could reflect differences in water quality with depth. Specific conductance and sulfate, bicarbonate, and calcium concentrations tend to be largest in the southeastern corner of the region.

The Northeast region was defined primarily on the basis of elevated values of specific conductance, chloride, sodium, and arsenic (figs. 17, 18, 22, and 25) compared with adjacent regions (table 3). Bicarbonate, calcium, and silica concentrations in several wells also are larger than those in adjacent regions (figs. 20, 21, and 23) and pH values are smaller (fig. 24). Although calcium/carbonate + bicarbonate is the most common water type among wells of the Northeast region, five other water types also are present (fig. 28). These other water types were observed mainly in wells having a total depth of about 1,600 feet or greater and could reflect differences in water quality with depth. The elevated values of several parameters in the Northeast region indicate a localized source of ground water with relatively large dissolved-solids concentration. A plot of the ratio between equivalents of sulfate and of chloride (fig. 29) indicates that ground water in this region is particularly high in chloride relative to sulfate compared with all other regions.

The East Mesa region was defined primarily on the basis of small values of specific conductance, sodium, and arsenic (figs. 17, 22, and 25) relative to those in adjacent regions (table 3). Sulfate and silica concentrations also are small compared with those in the Central region (figs. 19 and 23). Silica concentrations tend to be larger in the southern part of the region than in the northern part (fig. 23), as do concentrations of chloride (fig. 18). All but one well in the East Mesa region produces water of the calcium/carbonate + bicarbonate type (fig. 28).

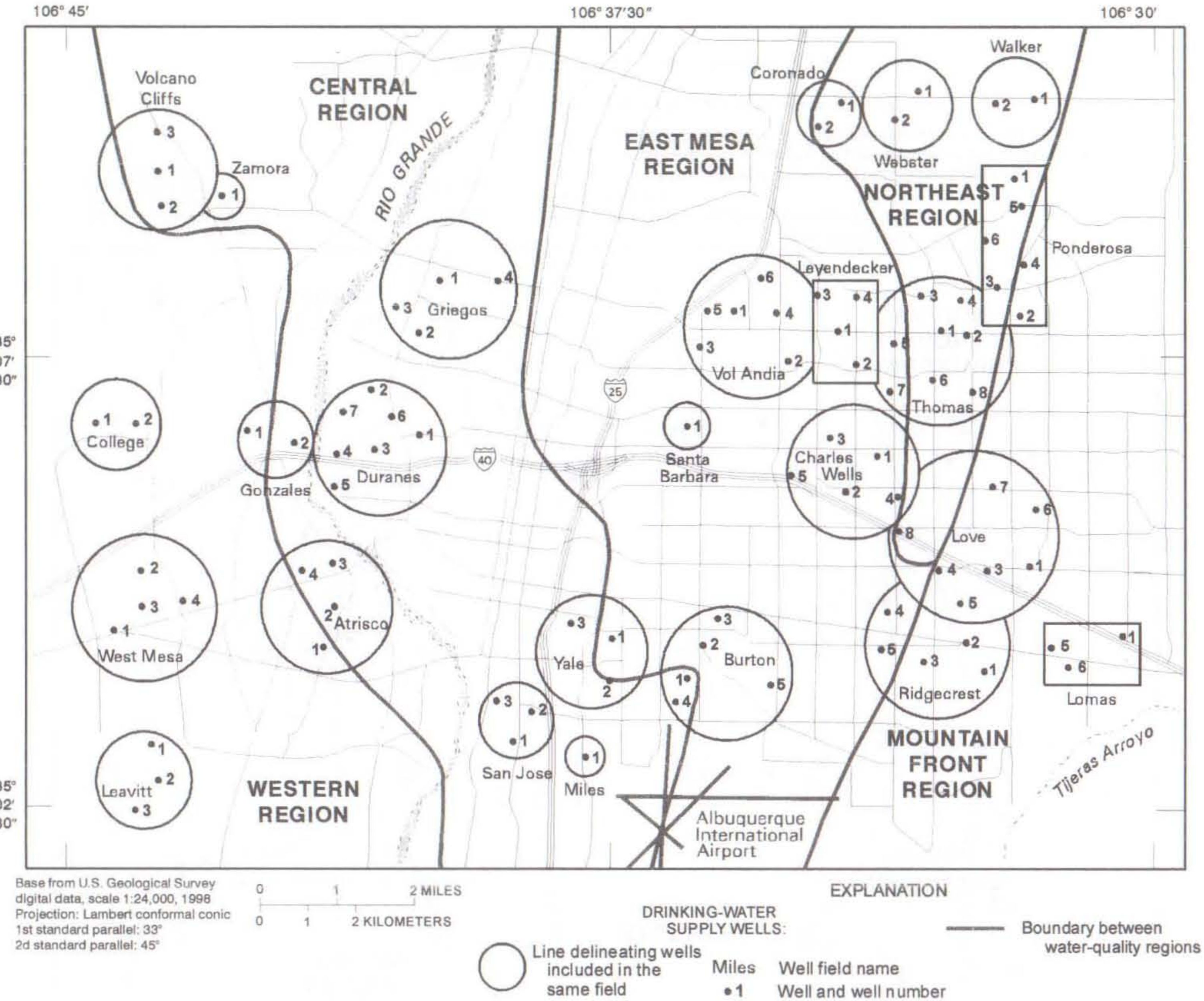


Figure 16. Locations of water-quality regions.

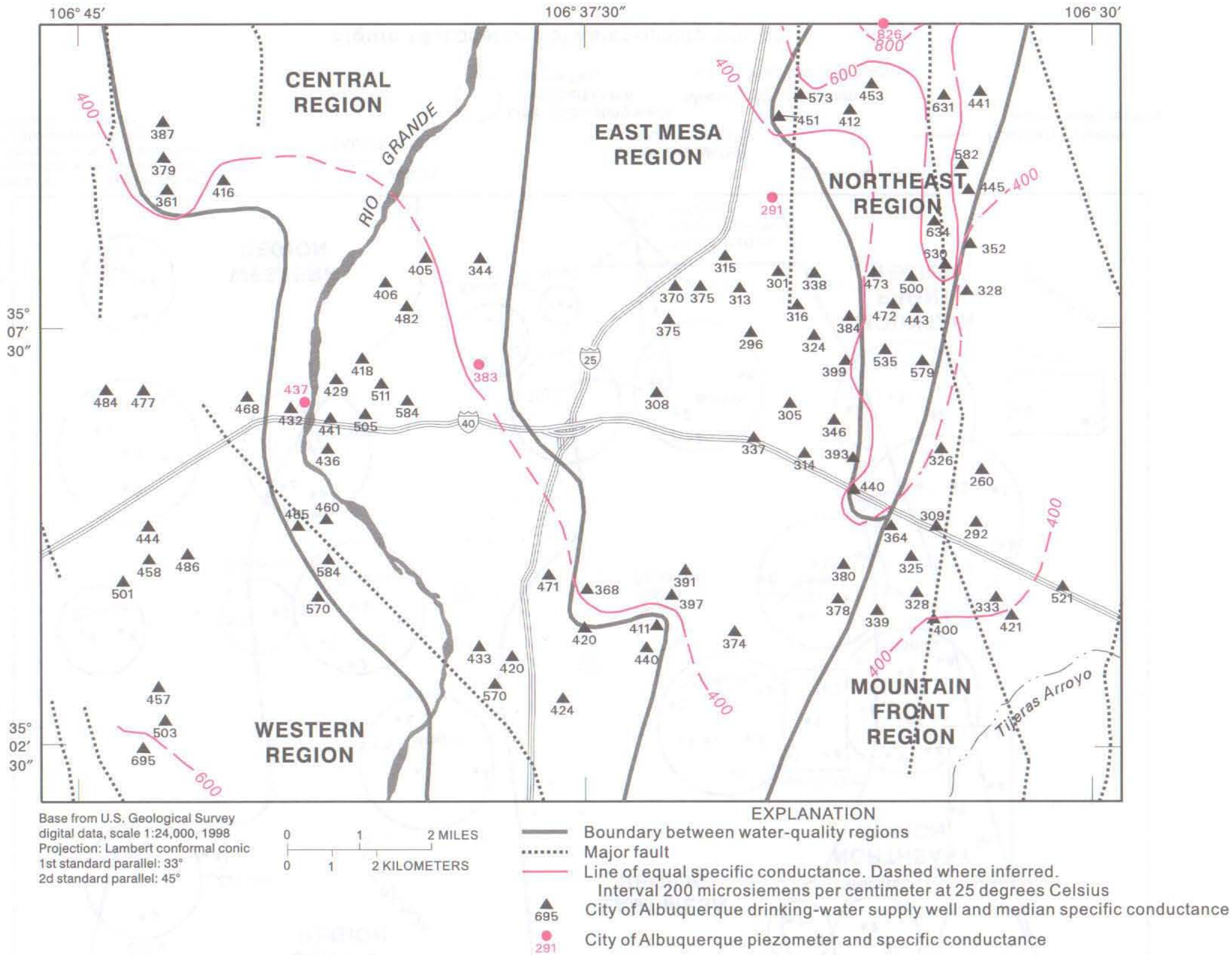
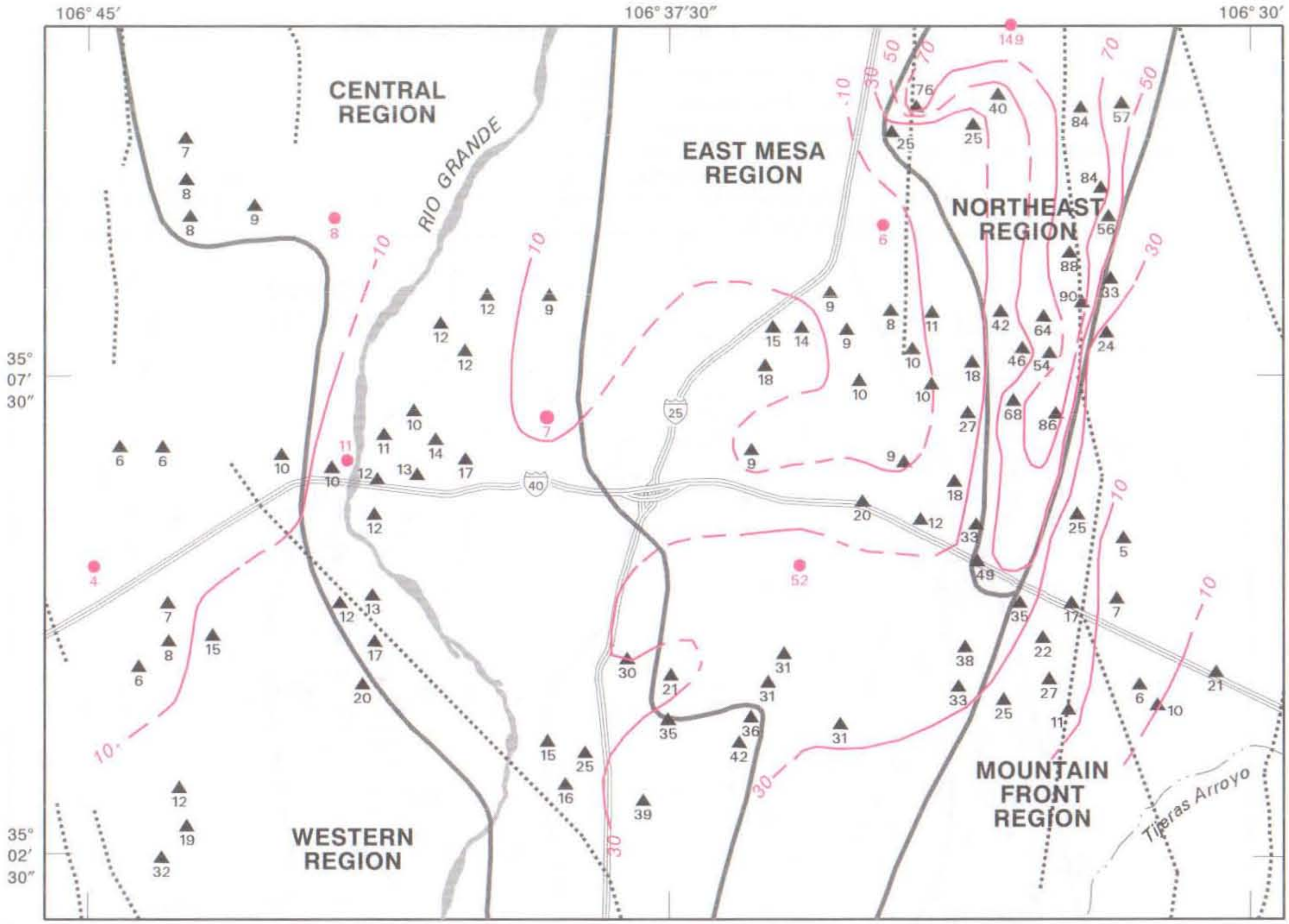


Figure 17. Specific conductance in selected wells.



Base from U.S. Geological Survey digital data, scale 1:24,000, 1998
Projection: Lambert conformal conic
1st standard parallel: 33°
2d standard parallel: 45°

0 1 2 MILES
0 1 2 KILOMETERS

EXPLANATION

- Boundary between water-quality regions
- Major fault
- Line of equal chloride concentration. Dashed where inferred. Interval 20 milligrams per liter
- 32 ▲ City of Albuquerque drinking-water supply well and median chloride concentration
- 11 ● City of Albuquerque piezometer and chloride concentration

Figure 18. Chloride concentration in selected wells.

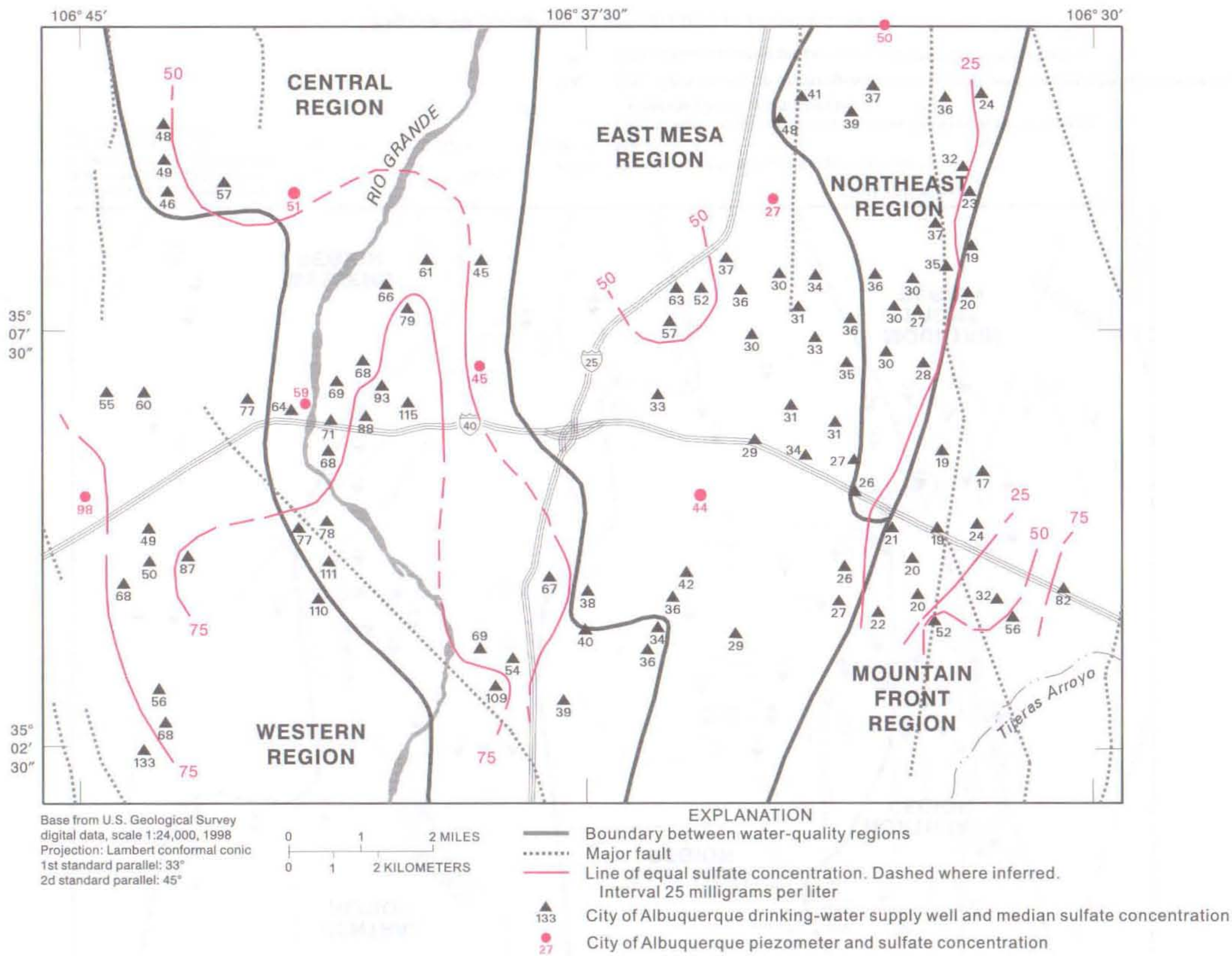


Figure 19. Sulfate concentration in selected wells.

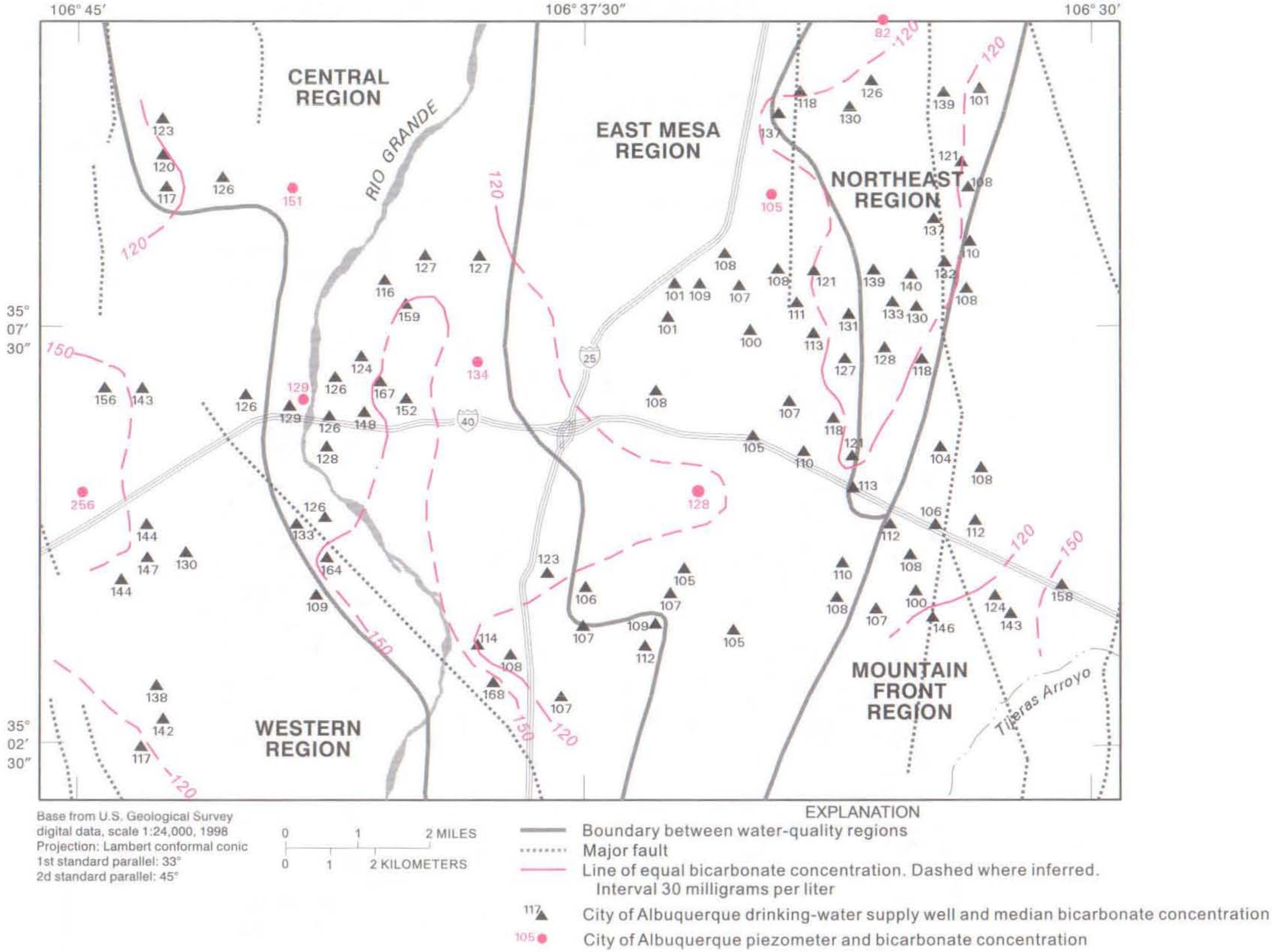


Figure 20. Bicarbonate concentration (as calcium carbonate) in selected wells.

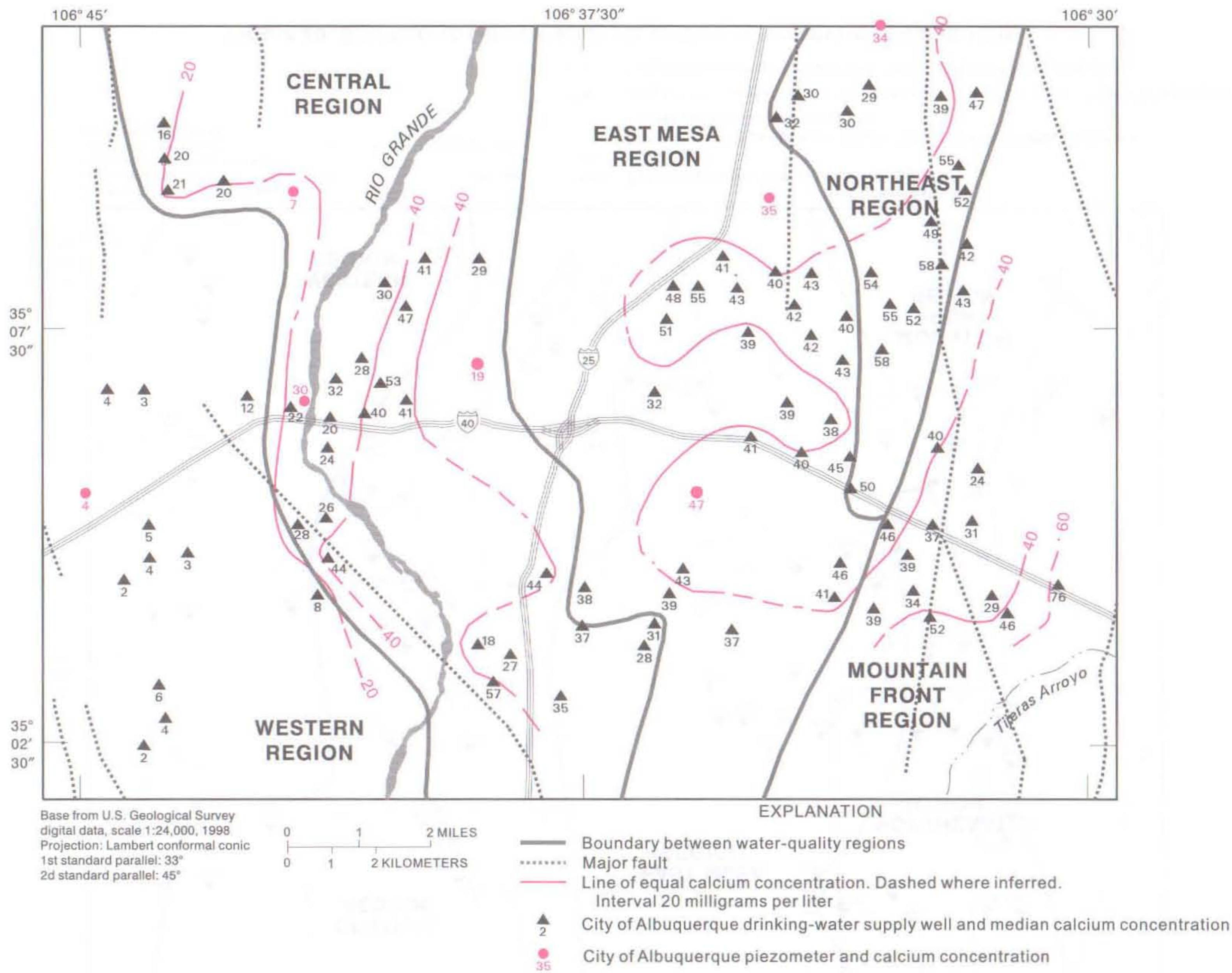
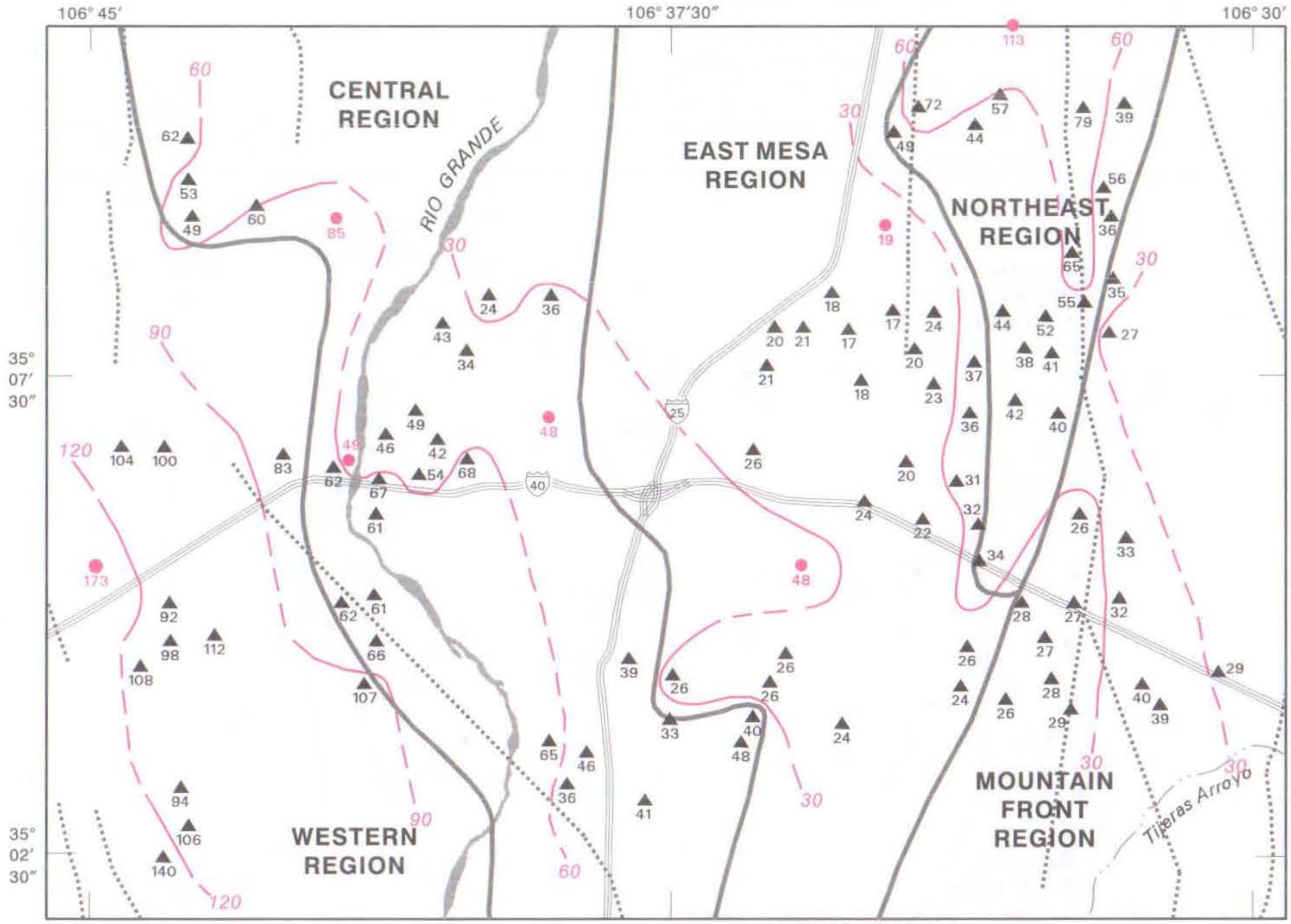


Figure 21. Calcium concentration in selected wells.



Base from U.S. Geological Survey
digital data, scale 1:24,000, 1998
Projection: Lambert conformal conic
1st standard parallel: 33°
2d standard parallel: 45°

0 1 2 MILES
0 1 2 KILOMETERS

EXPLANATION

Boundary between water-quality regions

Major fault

Line of equal sodium concentration. Dashed where inferred. Interval 30 milligrams per liter

140 City of Albuquerque drinking-water supply well and median sodium concentration

19 City of Albuquerque piezometer and sodium concentration

Figure 22. Sodium concentration in selected wells.

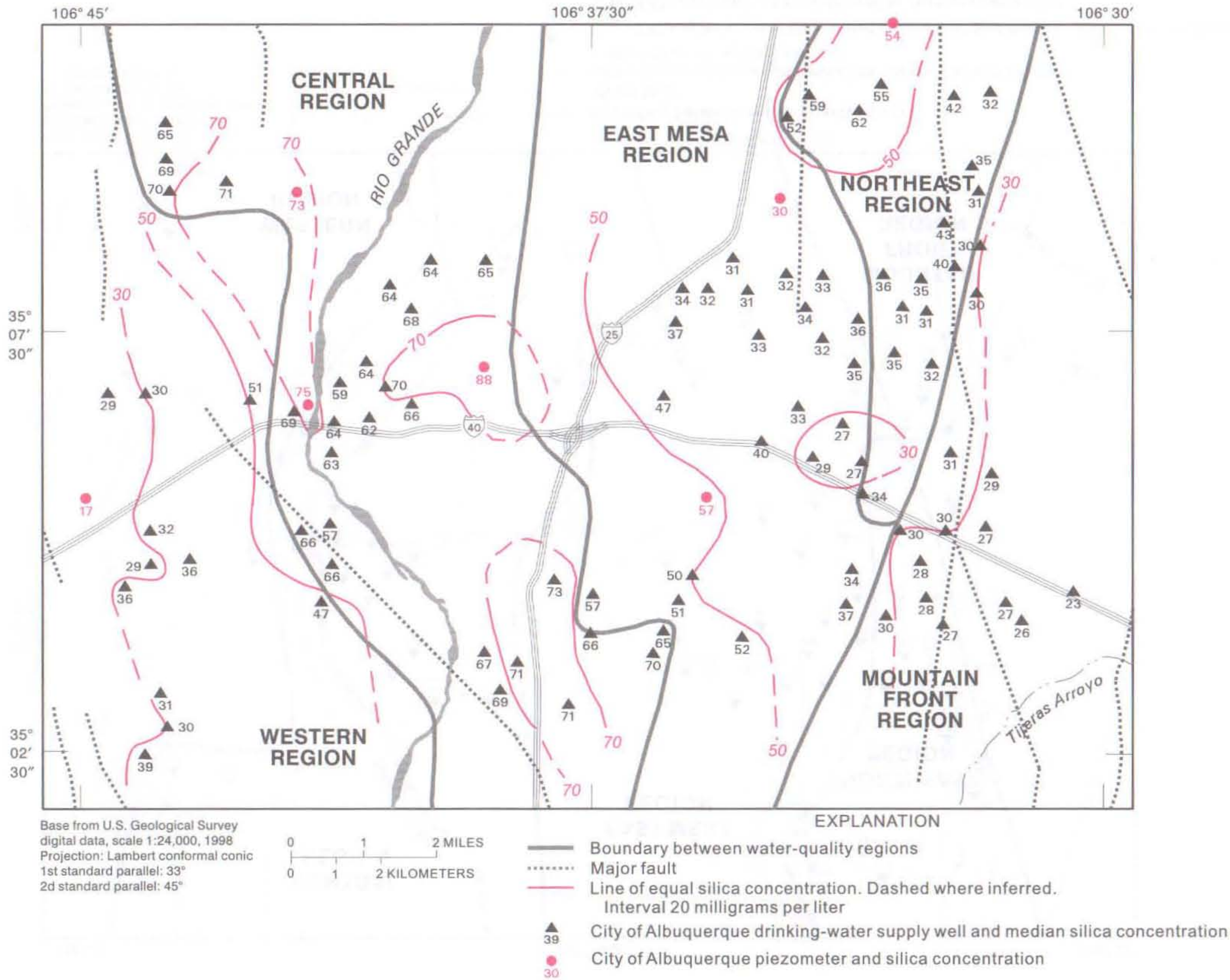


Figure 23. Silica concentration in selected wells.

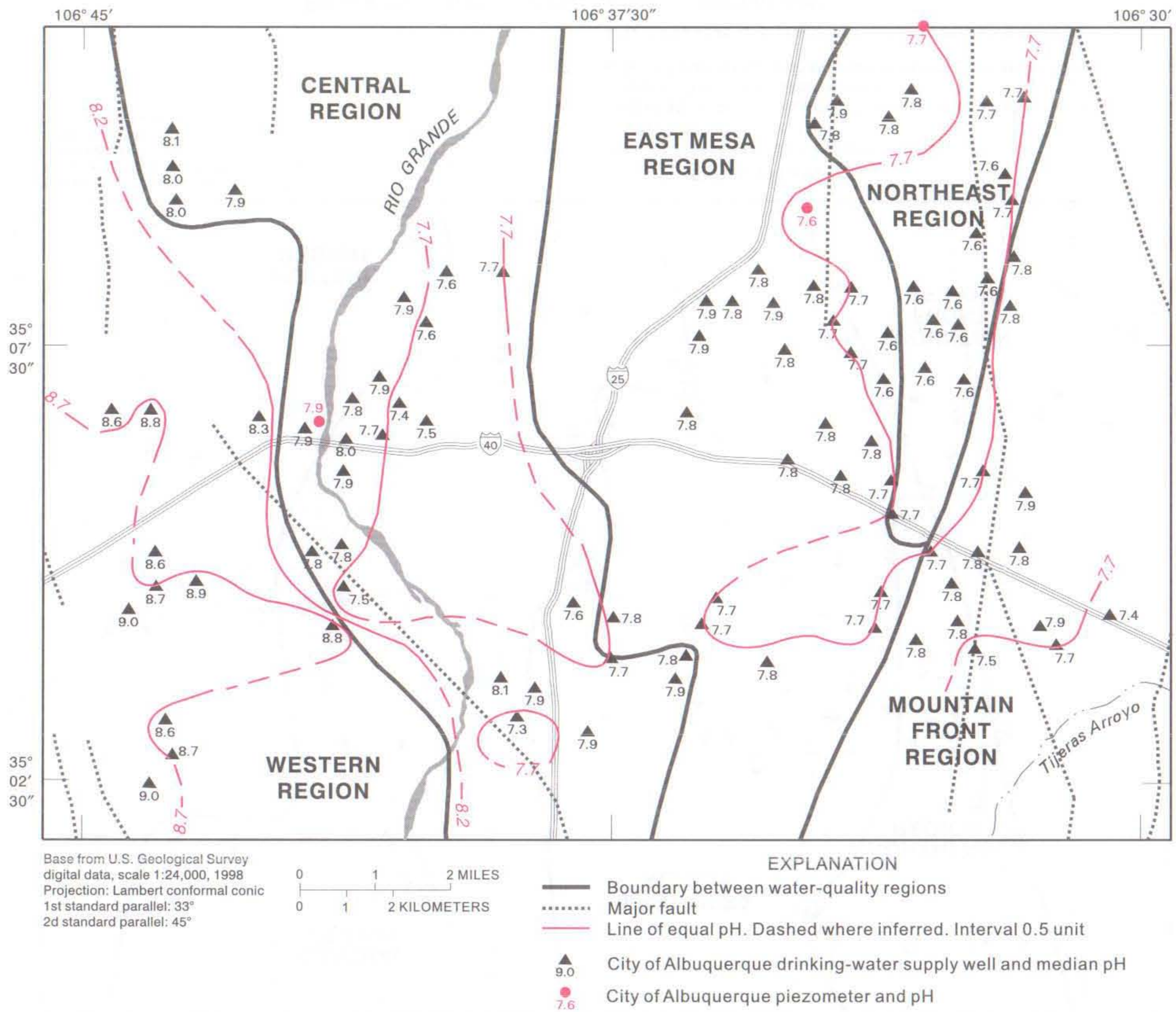
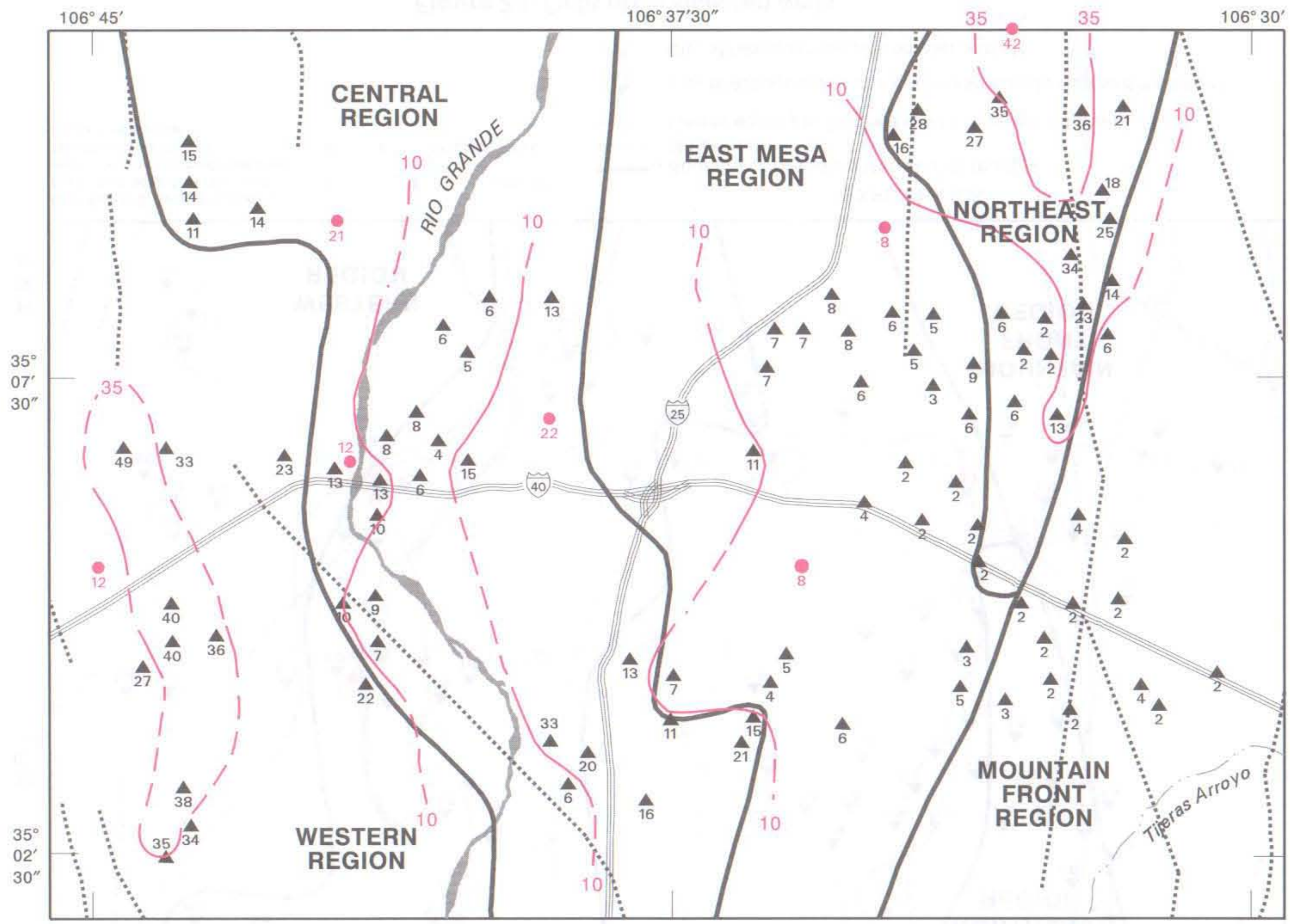


Figure 24. Field pH in selected wells.



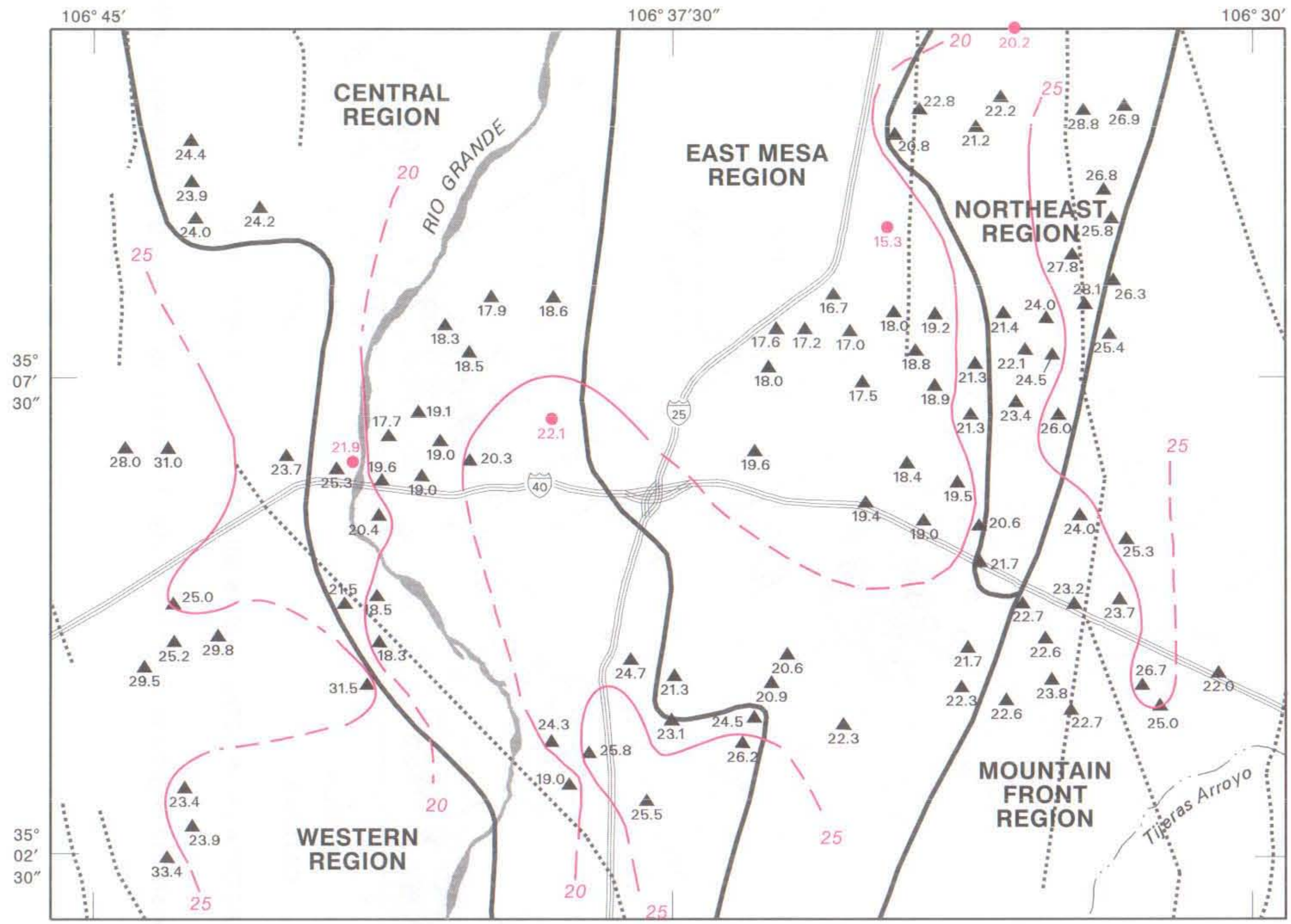
Base from U.S. Geological Survey digital data, scale 1:24,000, 1998
Projection: Lambert conformal conic
1st standard parallel: 33°
2d standard parallel: 45°

0 1 2 MILES
0 1 2 KILOMETERS

EXPLANATION

- Boundary between water-quality regions
- Major fault
- Line of equal arsenic concentration. Dashed where inferred. Interval 25 micrograms per liter
- ▲ 35 — City of Albuquerque drinking-water supply well and median arsenic concentration
- ● 8 — City of Albuquerque piezometer and arsenic concentration

Figure 25. Arsenic concentration in selected wells.



Base from U.S. Geological Survey digital data, scale 1:24,000, 1998
Projection: Lambert conformal conic
1st standard parallel: 33°
2d standard parallel: 45°

0 1 2 MILES
0 1 2 KILOMETERS

EXPLANATION

- Boundary between water-quality regions
- Major fault
- Line of equal water temperature. Dashed where inferred. Interval 5 degrees Celsius
- 33.4 City of Albuquerque drinking-water supply well and median water temperature
- 15.3 City of Albuquerque piezometer and water temperature

Figure 26. Water temperature in selected wells.

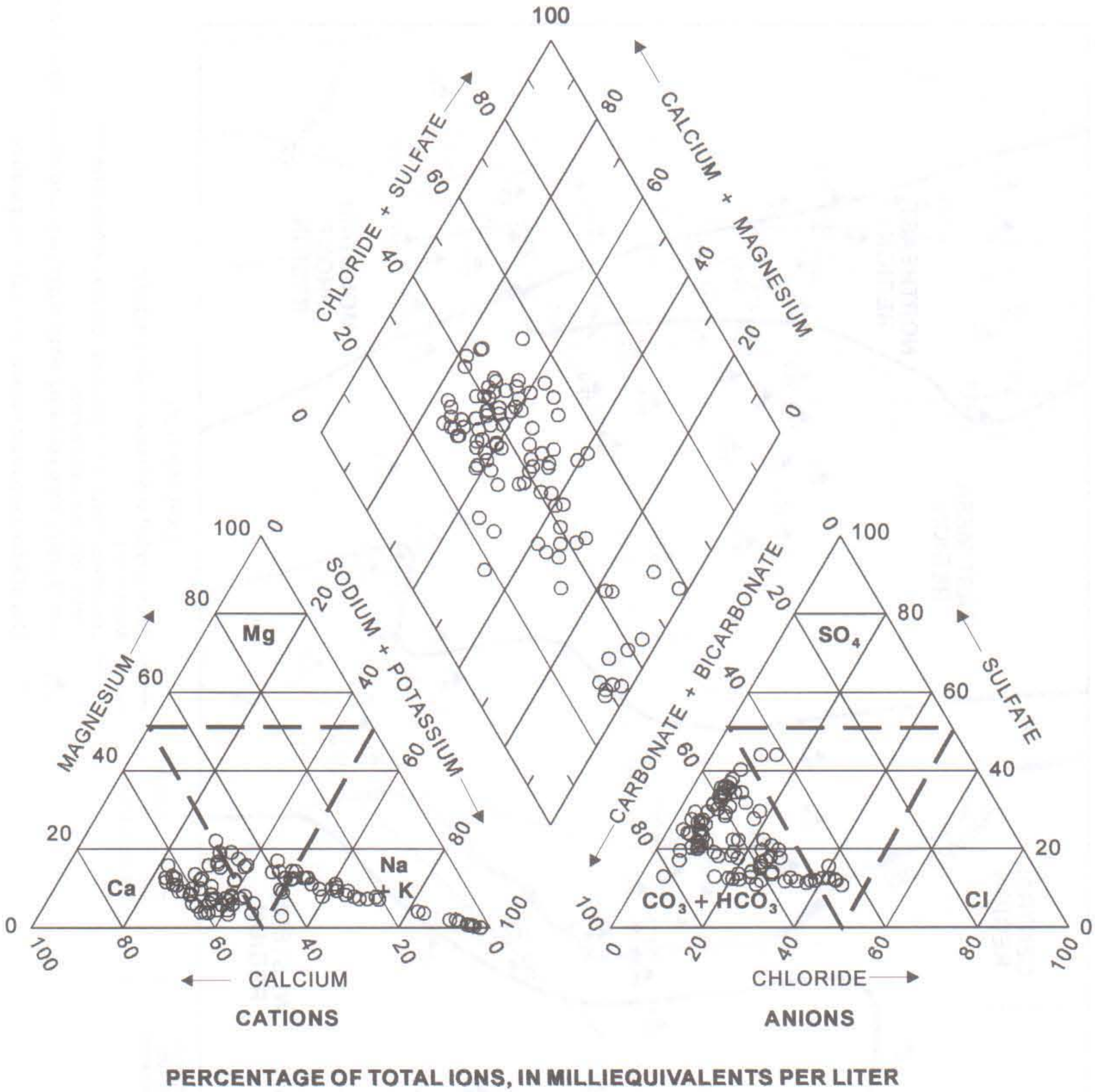


Figure 27. Compositions of ground water from City of Albuquerque drinking-water supply wells.

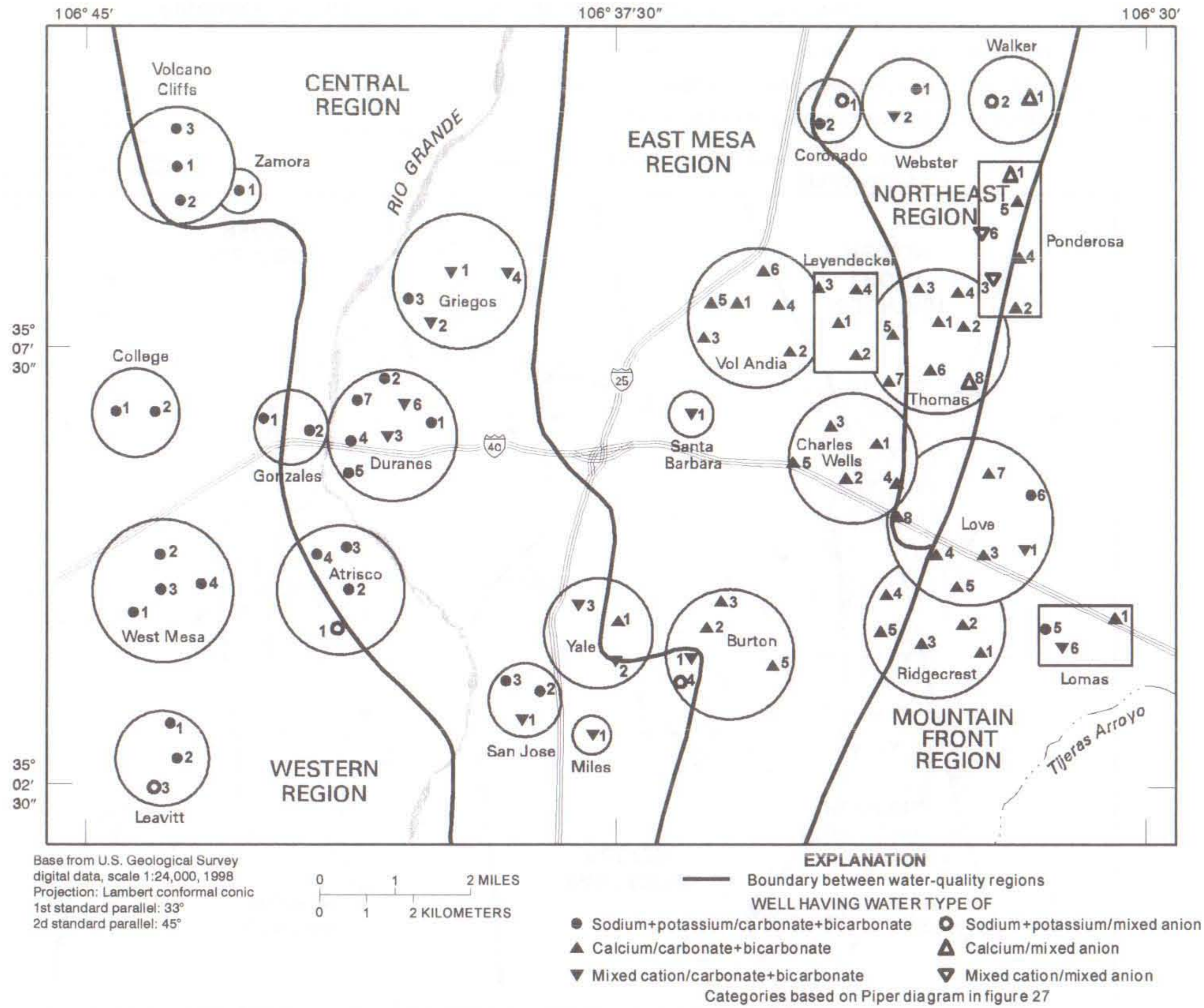


Figure 28. Water types in City of Albuquerque drinking-water supply wells.

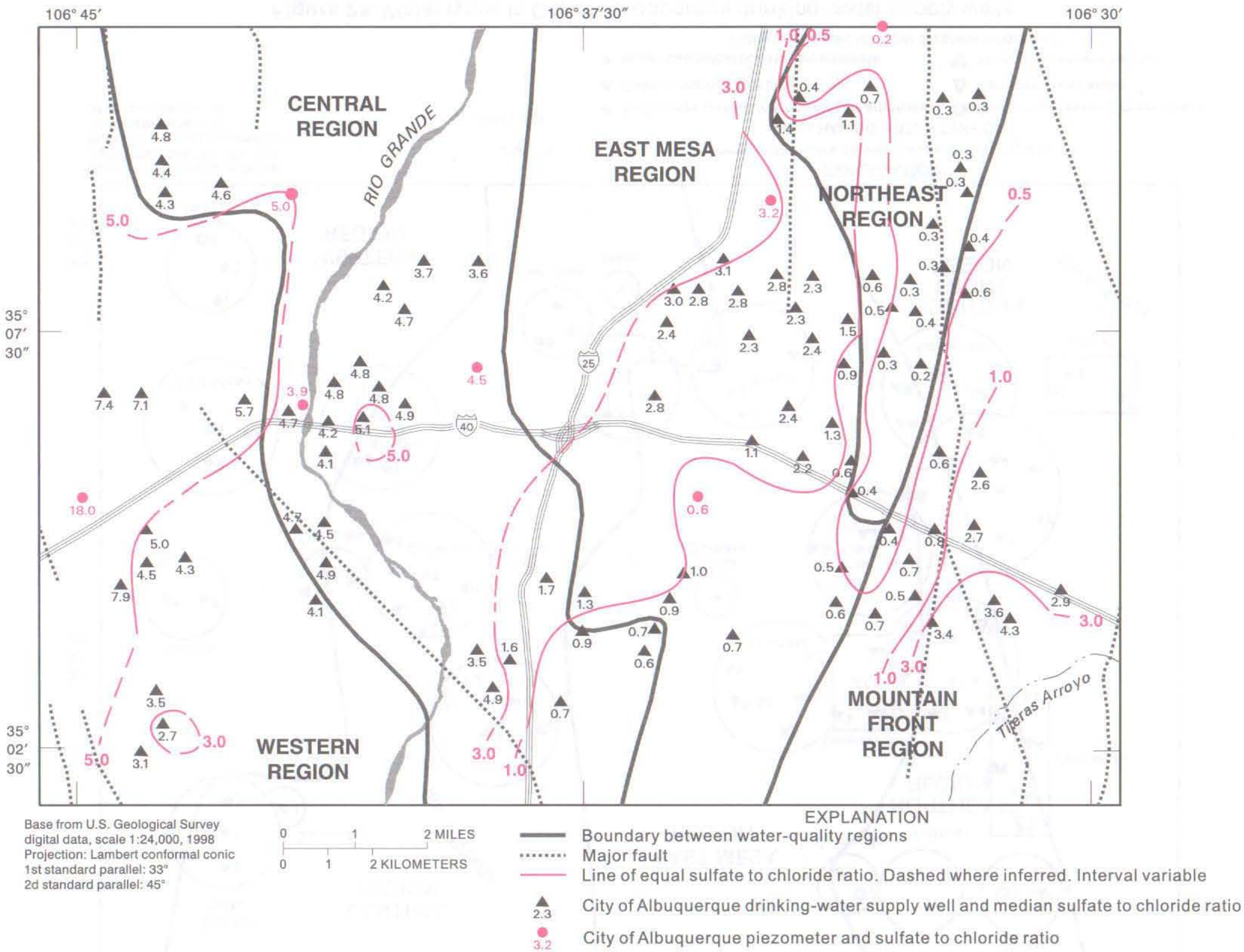


Figure 29. Sulfate to chloride ratio (in equivalents) in selected wells.

Table 3. Median values of water-quality parameters for each water-quality region delineated in the study area

[mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius (deg. C)]

Water-quality region (fig. 16)	Median calcium concentration (mg/L)	Median sodium concentration (mg/L)	Median bicarbonate concentration (mg/L as $CaCO_3$)	Median sulfate concentration (mg/L)	Median chloride concentration (mg/L)	Median silica concentration (mg/L as SiO_2)	Median arsenic concentration (µg/L)	Median field pH (standard units)	Median water temperature (deg. C)	Median specific conductance (µS/cm)
Western	3.9	104	142	67.9	9.9	32.4	34.6	8.7	28.0	484
Central	29.4	48.8	126	67.1	12.4	66.0	11.4	7.8	20.4	432
East Mesa	41.1	23.9	108	33.6	16.6	34.0	5.5	7.8	19.3	357
Northeast	52.0	44.1	130	31.7	56.9	34.6	18.0	7.6	24.0	473
Mountain Front	39.7	28.3	109	20.5	21.4	28.6	2.0	7.8	23.8	331

The Central region was defined primarily on the basis of values of specific conductance, calcium, sodium, silica, and arsenic (figs. 17, 21, 22, 23, and 25) compared with adjacent regions (table 3). Silica concentrations are substantially larger than those in any other region, whereas values of the other four parameters tend to be intermediate between those in the adjacent East Mesa and Western regions. Values of pH in the Central region typically are much smaller than those in the Western region (fig. 24). Wells of the region commonly produce water of either the sodium + potassium/carbonate + bicarbonate or mixed cation/ carbonate + bicarbonate type (fig. 28). Except in the southeastern part of the region, ratios of the equivalents of sulfate to chloride tend to be between 3.5 and 5.0 (fig. 29), with a median of 4.4, which is very similar to the median ratio of 4.65 for water in the Rio Grande.

The Western region was defined primarily on the basis of elevated values of specific conductance, sodium, pH, and arsenic (figs. 17, 22, 24, and 25) and small values of calcium (fig. 21) compared with all other regions (table 3). Concentrations of bicarbonate (fig. 20 and table 3) also tend to be the largest in any region, whereas chloride concentrations (fig. 18) tend to be the smallest. Water temperatures (fig. 26) also generally are higher than those in other regions, even though most wells in the Western region are not unusually deep. Most wells in the region produce water of the sodium + potassium/carbonate + bicarbonate type (fig. 28). Two wells that produce water of the sodium + potassium/mixed anion type are screened at greater depths than nearby wells and could reflect differences in water quality with depth.

Significance of Areal Patterns in Water Quality

Regions of similar water quality within the study area are oriented primarily north to south. This orientation is consistent with the orientation of water-quality zones delineated by Plummer and others (2001) for the entire Middle Rio Grande Basin using the chemical and isotopic composition of ground water. Among other isotopes, the Plummer and others (2001) study includes data for deuterium and oxygen-18 in water, which can be used to distinguish between possible sources of recharge, and data for carbon-14, which can be used to determine ground-water ages. Within the study area for this investigation, Plummer and others (2001) identified four water-quality zones that represent four different sources of recharge (fig. 30): mountain-front recharge along the Sandia Mountains (Eastern Mountain Front zone), seepage from the Rio Grande (Central zone), recharge from the Jemez Mountains north of the basin (West-Central zone), and infiltration from Tijeras Arroyo (Tijeras Arroyo zone). The water-quality regions defined as part of the current study differ somewhat from those defined by Plummer and others because the current study divides the study area into more detailed regions (with the exception of delineating the area of influence of Tijeras Arroyo) and delineates the regions on the basis of only major- and minor-element chemistry.

The orientation of both water-quality regions defined as part of the current study and defined by Plummer and others (2001) implies that ground-water flow through the study area has historically been oriented primarily north to south. In particular, the distributions of specific conductance and chloride (figs. 17 and 18), which can be expected to be conservative, are generally consistent with ground-water flow from north to south, with only very small components of flow from east to west. Predevelopment hydraulic-head maps (figs. 4 and 5) show a stronger component of westerly ground-water flow than is indicated by the water-quality regions. This lack of correspondence could be a result of the different time scales or the somewhat different depths represented by water quality as opposed to the hydraulic-head maps. Plummer and others (2001) indicated that the age of ground water in the study area (time since recharge) generally is thousands of years. Because the distribution of water quality reflects primarily ground-water movement and changes on the time scale of ground-water flow, it may represent conditions that existed in the ground-water flow system of the study area a few thousand years ago. In contrast, hydraulic heads can respond relatively quickly to changes in the quantity and distribution of recharge and discharge in a ground-water system, so predevelopment hydraulic-head maps may represent conditions that existed within only the last few hundred years. Also, relative to the water-quality data, most of the hydraulic-head data used to create available maps reflect conditions in shallower parts of the aquifer.

The location and dilute waters of the Mountain Front region indicate that the primary source of ground water to the region probably is mountain-front recharge from along the Sandia Mountains, which is consistent with the conclusions of Plummer and others (2001). Hydraulic-head maps also support this conclusion.

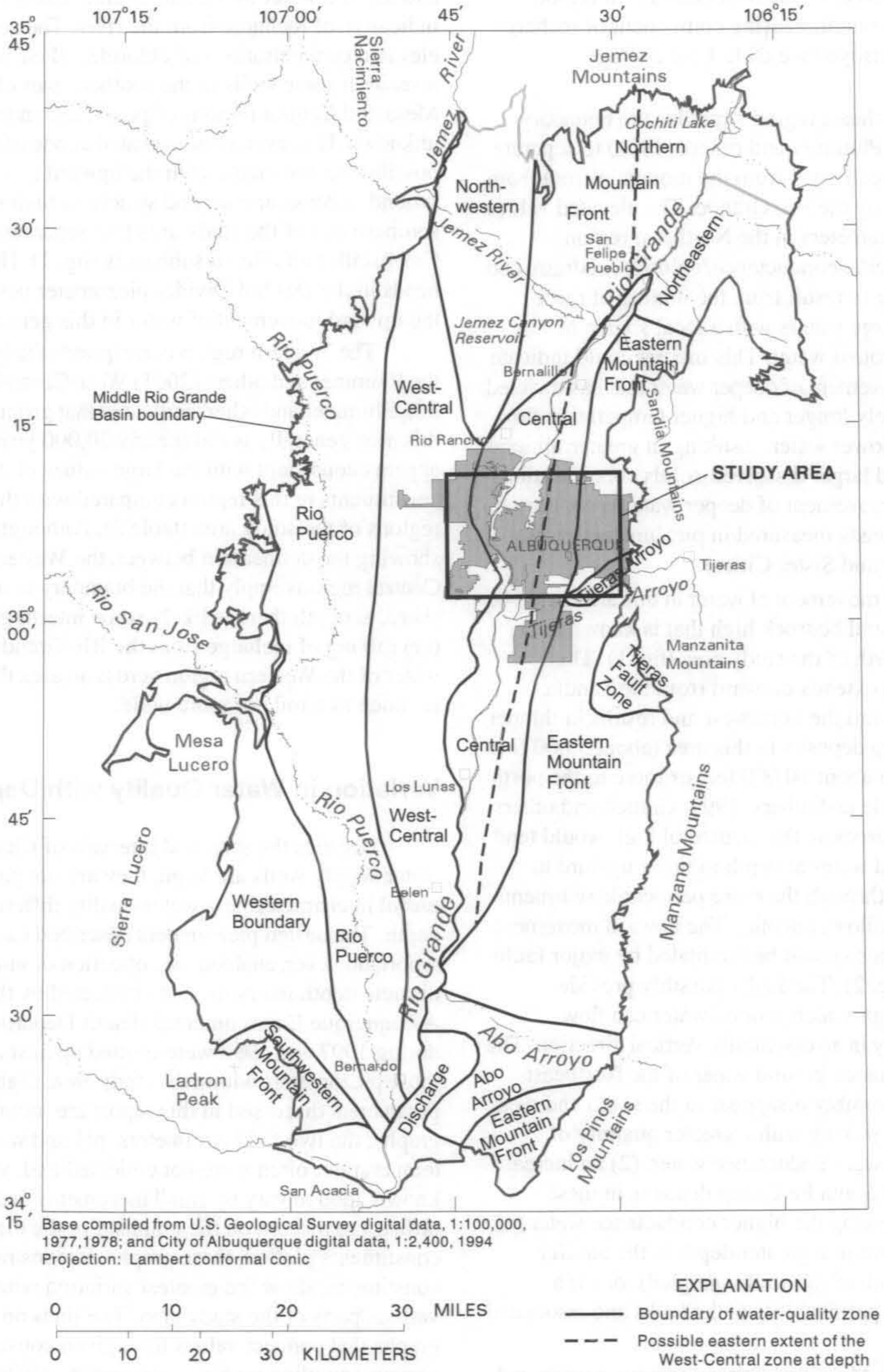


Figure 30. Water-quality regions defined by Plummer and others (2001) for the Middle Rio Grande Basin.

Increases in specific conductance and sulfate, bicarbonate, and calcium concentrations in the southeastern corner of the Mountain Front region probably reflect an increasing component of recharge from Tijeras Arroyo (see table 1 for average chemistry).

The Northeast region straddles the boundary designated by Plummer and others (2001) to separate ground water recharged from the mountain front from that recharged by the Rio Grande. The elevated values of multiple parameters in the Northeast region (including specific conductance, chloride, sodium, and arsenic) appear to result from the mixing of these different recharge waters with a local source of mineralized ground water. This mixing could indicate the upward movement of deeper water that has traveled along a relatively longer and higher temperature flow path than shallower water, resulting in greater mineral dissolution and larger dissolved-solids concentration. Such upward movement of deeper water is supported by hydraulic heads measured in piezometers in this area (Nor Este and Sister Cities).

Upward movement of water in this area could be due to a structural bedrock high that is known to be located just north of the study area (fig. 1). This structural high extends outward from the Sandia Mountains toward the northwest and results in thinner Santa Fe Group deposits in this area (about 5,000 feet compared with about 10,000 feet or more to the north and south) (Cole and others, 1999; Grauch and others, 1999). The bedrock in this structural high would tend to force ground water at depth to move upward to maintain flow through the more permeable sediments that exist at shallower depths. The upward movement of deep water also could be facilitated by major faults in this area (fig. 2). The faults possibly provide conduits through which ground water can flow relatively easily in an essentially vertical direction. The higher conductance ground water of the Northeast region could possibly disappear to the south and west because of (1) mixing with a greater quantity of surrounding lower conductance water, (2) an increase in thickness of Santa Fe Group deposits in these directions, allowing the higher conductance water to once again move to a greater depth in the aquifer (below the depth of the wells sampled), or (3) a decrease in the permeability of the faults and associated upwelling.

The East Mesa and Central regions correspond well to the Plummer and others (2001) Central zone (fig. 30). Similarities between the sulfate to chloride ratios in water from most wells in the Central region and surface water in the Rio Grande likely are indicative of recharge from the river. The source of elevated concentrations of chloride, silica, and (or) arsenic in some wells in the southern part of the East Mesa and Central regions (figs. 18, 23, and 25) is unknown. However, these elevated concentrations may possibly be associated with the upward movement of ground water over a second structural high near the southern end of the study area that separates the Calabacillas and Belen subbasins (fig. 1). Hydraulic heads in the Del Sol Divider piezometer nest support the upward movement of water in this general area.

The Western region corresponds fairly well to the Plummer and others (2001) West-Central zone (fig. 30). Plummer and others indicated that ground water in this area generally is old (nearly 20,000 years), which appears consistent with the large values of most constituents in this region compared with the other regions of the study area (table 3). Although figures showing the delineation between the Western and Central regions imply that the boundary is relatively sharp, at depth there is likely some interfingering and (or) mixing of recharge from the Rio Grande with water of the Western region across an area that may be as much as a mile or more wide.

Variation in Water Quality with Depth

Because the screened intervals of City drinking-water supply wells are large, they are not particularly useful in characterizing water-quality differences with depth. The nested piezometers described earlier in this report, however, enabled the collection of samples from discrete depth intervals. Data collected by the City of Albuquerque Environmental Health Department during 1997 and 1998 were plotted against depth for those piezometers within the study area. Eight of the 10 parameters discussed in this report are included on graphs; the two field parameters, pH and water temperature, often were not collected and, when known, tend to vary by small increments that would be difficult to discern on the graphs. For the eight constituents plotted, these graphs demonstrate which constituents show the greatest variation with depth in various parts of the study area. The lines on these graphs that connect values for a given constituent at various sampling points are intended only to aid in discerning differences with depth and are not meant to imply that the values change linearly between sampling points. Water types for individual piezometer nests are shown in figure 31. The Matheson Park piezometer nest is not discussed because no water-quality data currently (November 1999) are available for this nest.

Western Region

Chemical concentrations have large changes with depth in the 98th Street piezometer nest (fig. 32 and table 4), where the vertical flow gradient is predominantly downward. Concentrations of dissolved solids, chloride, sulfate, bicarbonate, sodium, and arsenic all generally increase between the water table and the deep completion, whereas concentrations of calcium and silica generally decrease. Concentrations of dissolved solids, chloride, sulfate, bicarbonate, and sodium have wide ranges compared with those from other piezometer nests (table 4). The largest changes in dissolved-solids, chloride, sulfate, calcium, and sodium concentrations in the 98th Street piezometer nest are between the mid-deep and deep piezometer completions. For all other constituents except arsenic, which shows the greatest change between the mid-shallow and mid-deep completions, the greatest change in concentration is between the water table and the mid-shallow completion. Despite the large differences in chemical concentrations with depth, relative even to regional differences in chemistry, three of the piezometer completions have the same water type of sodium + potassium/carbonate + bicarbonate (fig. 31). The deepest completion has a sodium + potassium/ mixed anion water type and a substantially larger percentage of chloride than the other completions.

The general pattern of increasing concentrations with depth in the 98th Street piezometer nest could reflect longer flow paths and travel times for water at greater depths, which would result in longer, higher temperature contact with aquifer materials and the possibility of more extensive alteration through such processes as dissolution and ion exchange. The possibility also exists that water at depth has had greater contact with rocks associated with the nearby Albuquerque volcanoes, which could tend to be more reactive than most other aquifer materials. As discussed earlier, the similarities in the magnitude and timing of water-level variations in the mid-deep and deep completions indicate good hydraulic connection. However, the large differences in water quality in these completions indicate, through the date of sampling, little or no mixing between water from the two zones.

Central Region

Water levels have shown that vertical ground-water movement in the vicinity of the Sierra Vista piezometer nest tends to be downward. Similar to those in the 98th Street nest, concentrations of dissolved solids, chloride, sulfate, bicarbonate, sodium, and arsenic in the Sierra Vista nest are smaller in the water-table interval than in the deepest completion. Although concentrations of calcium and silica are larger at the water table than at depth, the silica concentration is actually largest in the middle completion (fig. 33 and table 4). Changes in most chemical concentrations with depth are substantially smaller in this piezometer nest than in the 98th Street nest. All constituents except bicarbonate, calcium, and arsenic show a greater change in concentration between the middle and deep piezometer completions than between the water-table and middle completions. The cation type changes from mixed cation in the water-table completion to sodium + potassium in the middle and deep completions. The anion type changes from carbonate + bicarbonate in the water-table and middle completions to mixed anion in the deep completion, where the percentage of sulfate is much larger than in the other two completions (fig. 31).

Similar to the 98th Street piezometer nest, the general pattern of increasing concentrations with depth in the Sierra Vista piezometer nest could reflect longer flow paths and travel times for water at greater depth. Because this nest is located near the boundary between ground water that Plummer and others (2001) identified as seepage from the Rio Grande (Central region water) and recharge from the Jemez Mountains (Western region water), however, the differences likely reflect an increasing contribution of water from the Western region with depth. The large difference in water levels (about 27 feet), difference in timing of water-level variations, and difference in water quality between the middle and deep completions of the nest are all consistent with poor hydraulic connection and little or no mixing to date between water from these two zones. The relatively small difference in water levels (about 3 feet) between the two shallower completions could indicate a relatively good hydraulic connection, but water quality is somewhat dissimilar.

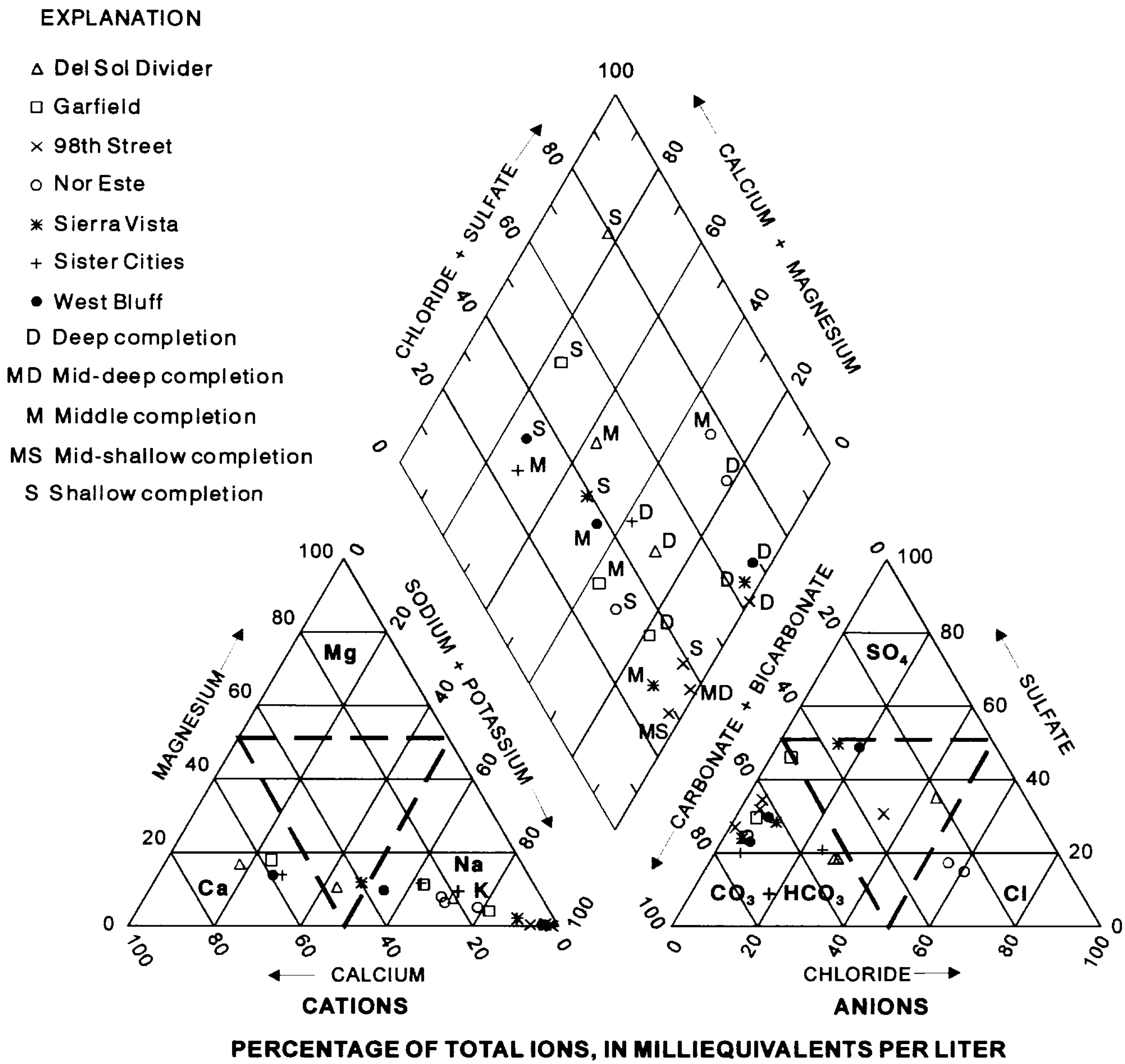


Figure 31. Compositions of ground water from deep piezometer nests.

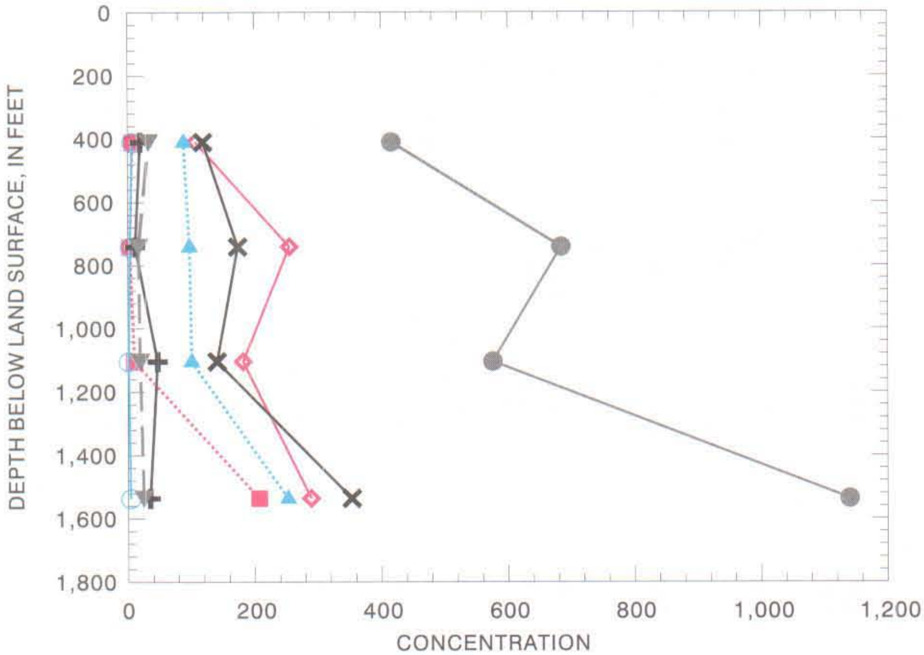
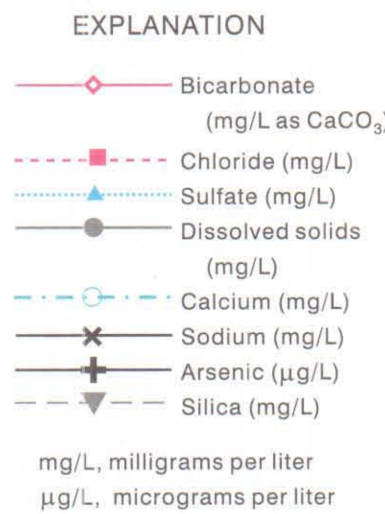


Figure 32. Concentrations of selected constituents in ground water from the 98th Street piezometer nest.



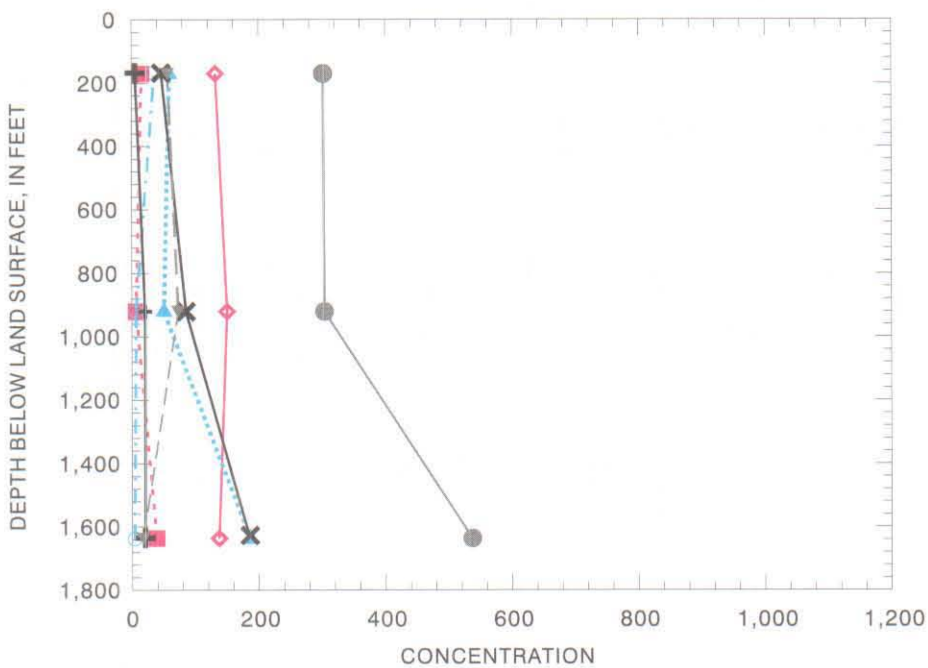


Figure 33. Concentrations of selected constituents in ground water from the Sierra Vista piezometer nest.

Table 4. Selected water-quality data for City of Albuquerque piezometer nests located in the study area

[Data from Doug Earp, City of Albuquerque Environmental Health Department, written commun., 1999. ft, feet; bls, below land surface; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; nd, no data]

Well name	Middle of screen (ft bls)	Sample date	Dissolved solids (mg/L)	Calcium (mg/L)	Sodium (mg/L)	Bicarbonate (mg/L as $CaCO_3$)	Sulfate (mg/L)	Chloride (mg/L)	Silica (mg/L)	Arsenic (µg/L)
Del Sol Divider-3	365	3/10/1999	559	104	29.1	75.9	124	116	39.8	2.00
Del Sol Divider-2	835	3/4/1999	nd	47.1	47.9	128	44.2	52.4	56.6	7.62
Del Sol Divider-1	1,560	3/9/1999	354	20.4	78.3	130	44.4	51.1	76.1	37.5
Garfield-3	63	1/29/1998	952	163	73.8	325	292	23.6	54.3	4.87
Garfield-2	562	1/29/1998	300	18.7	48.2	134	44.6	7.32	87.9	21.8
Garfield-1	1,003	1/29/1998	324	11.9	77.1	140	61.6	7.84	58.6	50.9
98th Street-4	411	6/17/1997	416	6.99	119	108	88.8	7.92	32.7	19.6
98th Street-3	742	7/4/1997	684	3.93	173	256	97.7	4.00	16.9	11.7
98th Street-2	1,105	6/18/1997	576	1.54	141	183	101	11.3	19.0	46.9
98th Street-1	1,537	6/17/1997	1,140	4.74	353	290	253	208	24.8	34.8
Nor Este-3	568	1/28/1998	384	22.0	74.4	156	53.4	8.83	61.3	20.4
Nor Este-2	1,186	1/28/1998	496	34.1	113	82.2	49.8	149	54.1	42.3
Nor Este-1	1,518	1/27/1998	500	23.6	131	91.1	57.7	137	40.3	61.9
Sierra Vista-3	170	3/22/1999	302	36.1	46.7	133	59.9	16.4	56.3	5.37
Sierra Vista-2	921	3/23/1999	304	7.21	85.3	151	51.2	7.62	73.1	21.0
Sierra Vista-1	1,637	3/22/1999	537	4.91	186	138	187	39.6	17.7	20.7
Sister Cities-3	400	nd	nd	nd	nd	nd	nd	nd	nd	nd
Sister Cities-2	792	3/17/1999	197	34.9	18.6	105	27.3	6.21	30.0	8.27
Sister Cities-1	1,301	3/16/1999	358	27.7	71.8	139	51.6	45.2	74.0	26.7
West Bluff, nest 2-3	153	1/5/1999	234	43.7	20.9	131	52.8	5.98	19.8	2.56
West Bluff, nest 1-2	682	1/6/1999	168	30.1	48.5	129	59.4	11.2	75.0	11.8
West Bluff, nest 1-1	1,088	1/5/1999	496	4.94	148	108	166	49.5	19.1	35.4

To simplify discussion of water-quality variations in the West Bluff piezometer nest, only the water-table, second deepest (mid-deep), and deepest of all six completions have been included in figure 34 and table 4. Water levels indicate that vertical flow between these piezometers generally tends to be downward. Concentrations of dissolved solids, chloride, sulfate, sodium, and arsenic are smaller in the water-table completion than in the deepest zone (fig. 34 and table 4). Although bicarbonate, calcium, and silica concentrations generally are larger in the water-table completion than in deeper zones, the silica concentration is largest in the mid-deep completion. The magnitudes of the ranges of chemical concentrations in the West Bluff piezometer completions are more similar to those in the Sierra Vista piezometer nest than to those in the 98th Street nest. Constituents show a greater change in concentration between the mid-deep and deepest completions than between the water-table and mid-deep completions. The cation type changes from calcium in the water-table completion to sodium + potassium in the mid-deep and deep completions. The anion type changes from carbonate + bicarbonate in the water-table and mid-deep completions to mixed anion in the deep completion, where the percentage of sulfate is much larger than in the other two completions (fig. 31).

Again, the general pattern of increasing concentrations with depth in the West Bluff piezometer nest may reflect longer flow paths and travel times for water at greater depth or a greater contribution of water from the Western region with depth. Water-level data are consistent with the Rio Grande as a source of recharge to shallow ground water. Large differences in water quality and temporal lag in water-level changes between the mid-deep and deep completions are consistent with poor hydraulic connection and little or no mixing to date between water from these two zones.

Concentrations of dissolved solids, chloride, sulfate, bicarbonate, and calcium in the Garfield piezometer nest are larger in the water-table completion than in deeper completions. Although concentrations of sodium, silica, and arsenic are smaller in the water-table completion than in the deepest zone, silica is largest in the middle completion (fig. 35 and table 4). Ranges in the concentrations of dissolved solids, sulfate, bicarbonate, calcium, and arsenic are large compared with other piezometer nests. All constituents except sodium and arsenic show a greater change in concentration between the water-table and the middle completion than between the middle and deep completions. In fact, the ranges in concentrations between the middle and deep completions are less than 30 mg/L (or micrograms per liter) for all constituents. The middle and deep completions have the water type of sodium + potassium/carbonate + bicarbonate, whereas the water-table completion has a water type of calcium/mixed anion (fig. 31).

The large concentrations of most major ions in water from the water table at the Garfield piezometer, combined with the relatively shallow depths to water at this site (generally less than 50 feet below land surface; fig. 11), imply that shallow ground water in this area could include a large contribution of recent recharge that either has been concentrated through evapotranspiration or has been altered by human activity. Such sources of recharge could include direct infiltration of precipitation, infiltration of irrigation water through canals or irrigated fields, or septic-tank effluent. As discussed previously, the timing of water-level fluctuations in the water-table completion of the piezometer indicates recharge from the irrigation system.

Water levels indicate downward gradients and relatively good hydraulic connection between all completions of the Garfield nest. The quality of water from the middle and deep completions is similar, which is consistent with water movement between these zones and (or) a common source of recharge from the Rio Grande. However, differences in the quality of water between the shallow and middle completions indicate little mixing to date between water near the water table and water at the middle completion.

East Mesa Region

Concentrations of dissolved solids, chloride, sulfate, and calcium in the Del Sol Divider piezometer nest are larger at the water table than in deeper completions, whereas concentrations of bicarbonate, sodium, silica, and arsenic are smaller at the water table (fig. 36 and table 4). Ranges in concentration are relatively small compared with those observed for other piezometer nests. Chloride, sulfate, bicarbonate, and calcium change more in concentration between the water-table and middle piezometer completions than between the middle and deep completions; sodium, arsenic, and silica concentrations change more between the middle and deep completions. The cation type of water at this site varies from calcium in the water-table completion to mixed cation in the middle completion to sodium + potassium in the deep completion. The anion

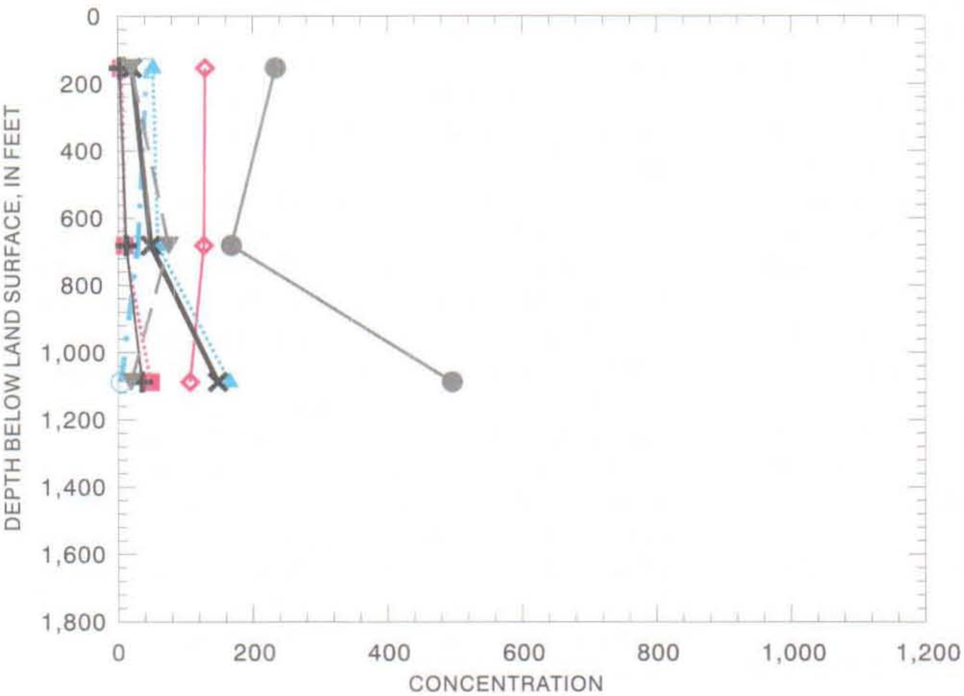
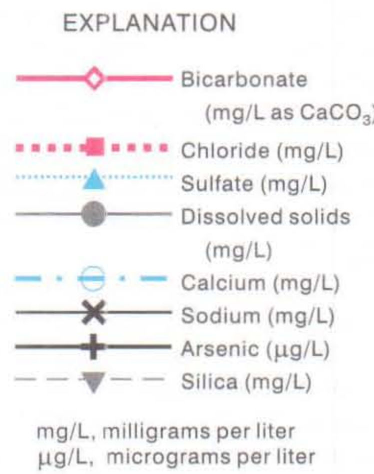


Figure 34. Concentrations of selected constituents in ground water from the West Bluff piezometer nest.



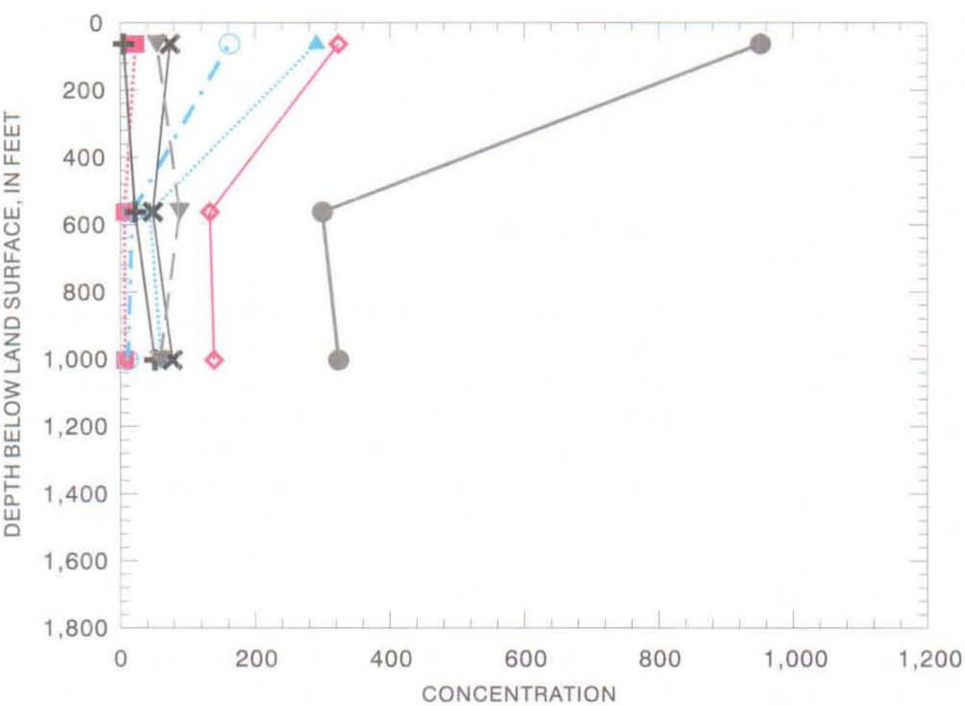


Figure 35. Concentrations of selected constituents in ground water from the Garfield piezometer nest.

type varies from mixed anion in the water-table completion, where the chloride percentage is relatively large, to carbonate + bicarbonate in the middle and deep completions (fig. 31).

Similar to the Garfield piezometer nest, shallower water at Del Sol has been mineralized to a greater degree than deeper water. Seasonal increases in water levels at the water table are consistent with local recharge. However, the substantially greater depth to water (nearly 350 feet) at this site compared with that at the Garfield site makes the likely source of such water difficult to determine. The quality of water near the water table does not appear consistent with the upward movement of ground water to the water table, although water levels indicate the potential for this during seasons of smaller pumpage. Water-level data for the middle and deep completions at the Del Sol nest indicate some hydraulic connection. The similarity in water quality between the two zones suggests water movement between the two zones or simply a similar source of water for the two zones.

Because sampling pumps cannot be lowered into the water-table piezometer completion in the Sister Cities piezometer nest because of a problem with the well casing, samples can be collected only from the middle and deep completions. Concentrations of dissolved solids, chloride, sulfate, bicarbonate, sodium, silica, and arsenic increase from the middle to the deep piezometer, whereas the concentration of calcium decreases (fig. 37 and table 4). Because data are available for only the two deepest piezometers, ranges in concentration calculated for the Sister Cities piezometer nest probably are not comparable to ranges calculated for the other nests studied. The water type changes from calcium/carbonate + bicarbonate in the middle completion to sodium + potassium/carbonate + bicarbonate in the deep completion (fig. 31).

The general pattern of increasing concentrations with depth at Sister Cities could reflect longer flow paths and travel times for water at greater depth or greater mixing with a mineralized source of water moving upward from depth in the general area of the Northeast region. Relatively small hydraulic gradients and differences in the timing of water-level variations indicate that water-quality differences between the two completions at this site could be maintained by poor hydraulic connection and little or no mixing to date between water from these two zones.

Northeast Region

Concentrations of dissolved solids, chloride, sulfate, calcium, sodium, and arsenic in the Nor Este piezometer nest generally increase between the water table and the deep completion, whereas concentrations of bicarbonate and silica decrease (fig. 38 and table 4). Ranges in concentration for several of the constituents being studied are small relative to other piezometer nests, but the ranges in chloride and arsenic concentration are relatively wide, at about 140 mg/L and 42 micrograms per liter (μg/L), respectively. All constituents except sulfate and silica change more in concentration between the water table and the middle piezometer completion than between the middle and deep completions. The water types at this site vary from sodium + potassium/carbonate + bicarbonate in the water-table completion to sodium + potassium/chloride in the middle and deep completions (fig. 31).

The general pattern of increasing concentrations with depth at Nor Este could reflect longer flow paths and travel times for water at greater depth or greater mixing with a mineralized source of water moving upward from depth in the Northeast region. Water-level data are consistent with the upward movement of deeper, more concentrated water. Water-level data also imply a relatively good hydraulic connection between all zones at this site, although water-quality differences indicate little or no mixing to date between water from the middle completion and water from the water table.

TEMPORAL VARIATION IN WATER QUALITY FROM INDIVIDUAL DRINKING-WATER SUPPLY WELLS

As discussed in the previous section, the quality of ground water in the study area shows substantial spatial variation. Because of such variation, the quality of water produced by an individual well could vary with time. The variation or lack of variation in the quality of water produced by an individual well could provide insight into how the aquifer in a particular area is responding to pumping stresses and, therefore, how the aquifer may react in the future under continued stresses.

If substantial variation (greater than that expected in association with laboratory and sampling methods) is observed in the quality of water from an individual well, then the relative amounts of waters of differing quality pumped from that well must be

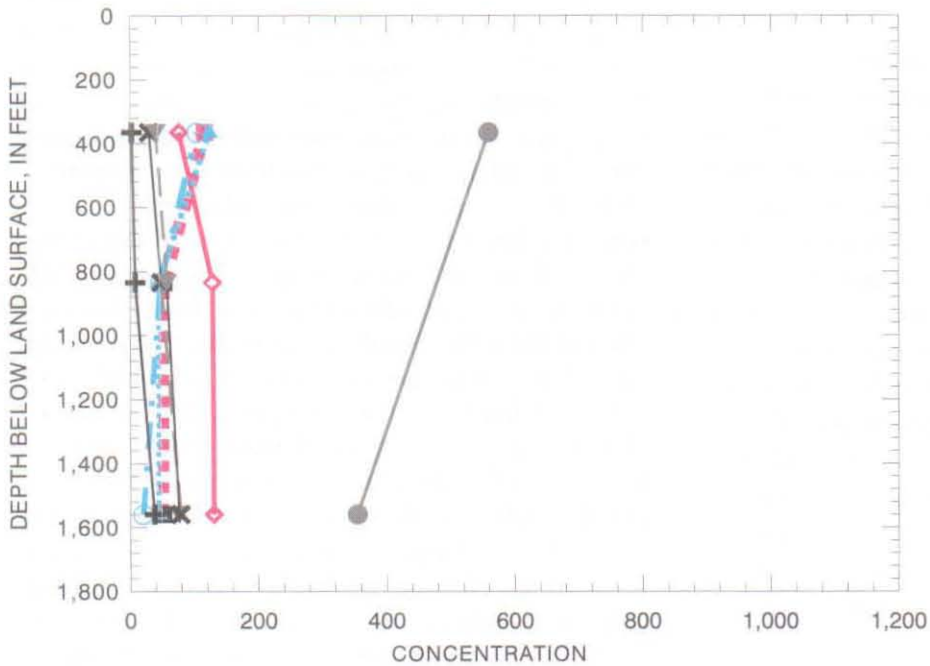
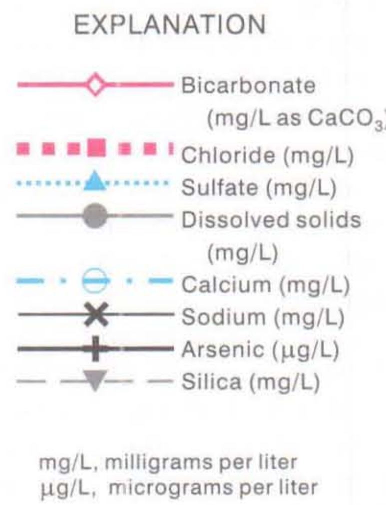


Figure 36. Concentrations of selected constituents in ground water from the Del Sol Divider piezometer nest.



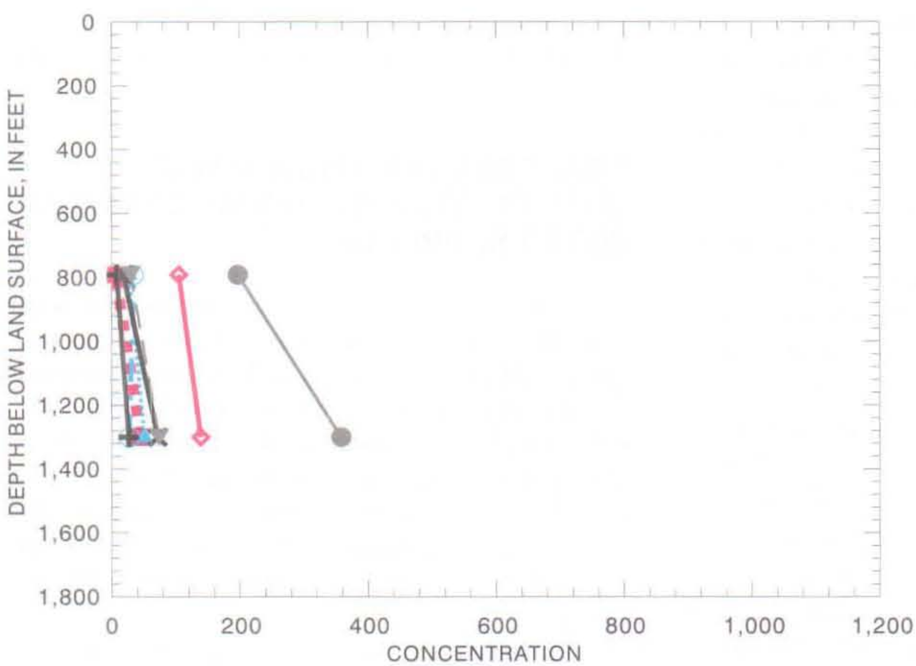


Figure 37. Concentrations of selected constituents in ground water from the Sister Cities piezometer nest.

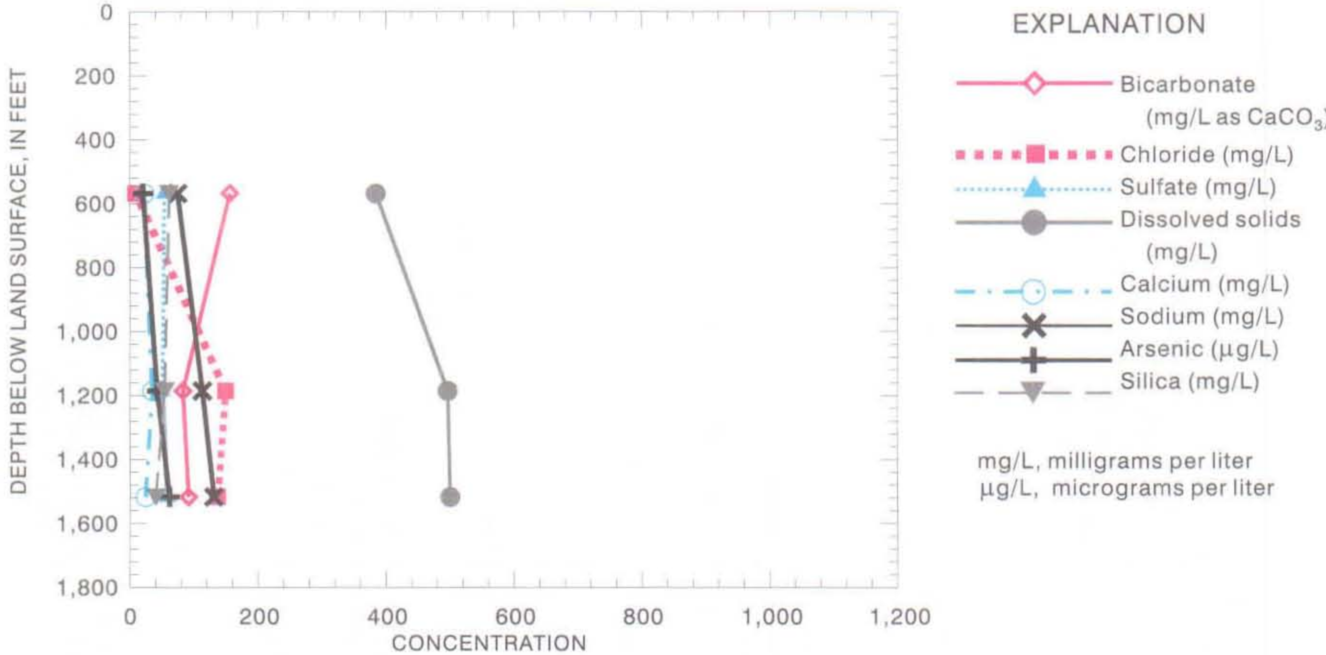


Figure 38. Concentrations of selected constituents in ground water from the Nor Este piezometer nest.

changing. The relative amounts of waters of different quality that are produced by an individual well could vary as a result of changes in the quality of water available within the areal capture zone of the well (Franke and others, 1998) or changes in the amounts of water contributed to the well from different depths of the aquifer (Reilly and Gibs, 1993) (fig. 39). Changes in ground-water flow direction resulting from drawdown of hydraulic head in areas of substantial pumpage can change the quality of water existing within the capture zone of a well. On the time scale that pumpage has altered flow directions in the study area (about 50 years), such changes can occur locally where waters having different recharge sources and (or) chemistries are in close proximity. Plugging of a well screen with time or changes in the distribution of hydraulic heads with depth as a result of pumping can change the amounts of water contributed to a well from different depths in the aquifer.

The manner in which water quality in an individual well varies with time can provide insight into the effects of changing aquifer conditions on the movement of water of different quality. For example, if the quality of water from a well trends consistently in one direction with time, then the relative contributions of differing waters to the well are changing consistently with time. A consistent change in these contributions likely is the result of a consistent change in the stress placed on different parts of the aquifer, such as through continually increasing drawdown of hydraulic head or continually advancing plugging of well screens. Such a time-related change can be useful in predicting the direction and possibly the magnitude of future changes in water quality. If the quality of water from the well shows a correlation with the amount of water pumped from the well per unit time, then the relative contributions of waters of differing quality to the well likely are associated with the localized effects on the aquifer of pumping from that well. In this case, the well owner might be able to operate the well in a manner that will optimize the quality of water it produces. If the quality of water produced by a well shows substantial variability, but that variability does not show any relation to time, pumpage, or any other known factors, then the variability must be due to a poorly understood process. As part of this study, the manner in which the quality of water produced by individual City drinking-water supply wells varied with respect to time and to the quantity of monthly pumpage was investigated.

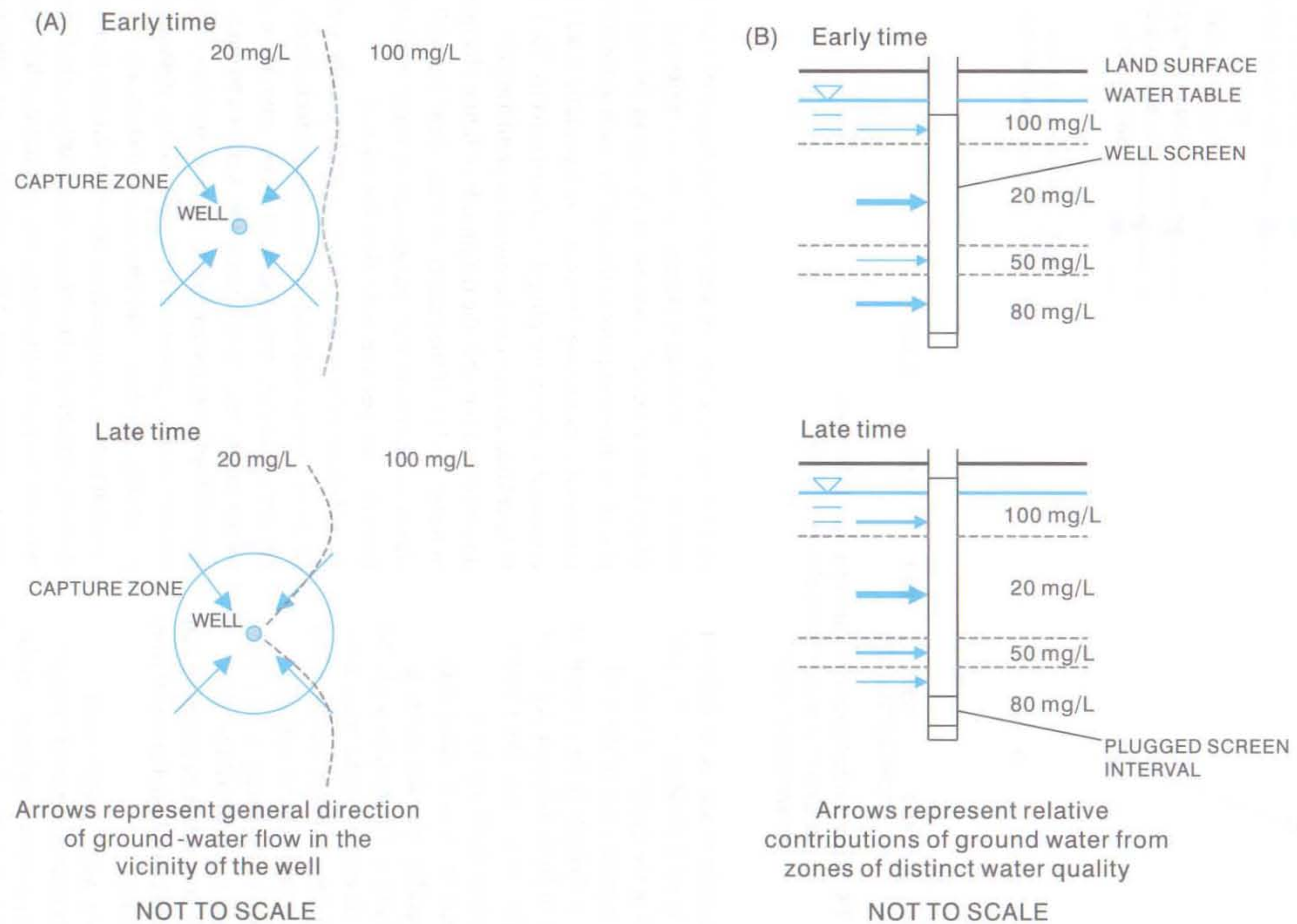


Figure 39. Possible mechanisms of change in ground-water quality from a well related to changes in (A) the quality of water present within the areal capture zone of the well as a result of pumpage and (B) the relative contribution of water from zones of distinct water quality as a result of screen plugging (mg/L, milligrams per liter).

Variability in Water-Quality Data

To investigate water-quality variability in individual City drinking-water supply wells with respect to particular parameters and with respect to other wells, the IQR was determined by well for each parameter (table 5). For dissolved solids, the largest IQR was 60 mg/L; for each well, the IQR was between 2.4 and 19.7 percent of the median concentration, which is fairly small. Among the major elements, the largest IQR was 20.1 mg/L or less for chloride, calcium, sodium, and silica and between 20 and 30 mg/L for sulfate and bicarbonate. In most cases, IQR's for the major elements did not exceed about one-third of the median well concentrations, with a few exceptions for calcium and chloride and one exception for sulfate. Therefore, most variability among the major constituents was not particularly large. For arsenic, the largest IQR was 12 μg/L; for all but five wells, the IQR was 33.3 percent of the median concentration or less. For field pH, the largest IQR was 0.57 unit and all IQR's were less than 7.5 percent of the median well value. For water temperature, the largest IQR was 6.8 degrees Celsius and all IQR's were less than 23 percent of the median well value. Overall, the data in table 5 demonstrate that variability for most parameters in most wells is quite small, indicating no substantial changes in water quality throughout much of the study area.

To determine which wells and areas generally have the most variable water quality, the number of constituents for which each well had one of the largest 10 IQR's was determined and plotted on a map (fig. 40). For most parameters, selecting wells having one of the largest 10 IQR's resulted in the selection of 10 wells, but for bicarbonate, field pH, and arsenic, more than 10 wells were selected because the 10th largest IQR was shared by more than one well. Wells that had one of the largest IQR's for more than 5 of the 10 parameters investigated were Duranes 1 and West Mesa 1 and 4; wells that had one of the largest IQR's for 4 or 5 parameters were Griegos 2 and Leavitt 2. Well fields that had no wells with one of the largest IQR's for more than one parameter were Burton, Coronado, Gonzales, Leyendecker, Miles, Santa Barbara, Volcano Cliffs, Walker, Webster, Yale, and Zamora. Overall, the incidence of large variability per well is higher in the Western and Northeastern regions and lower in the East Mesa and Mountain Front regions.

Temporal Trends in Water-Quality Data

To investigate time trends in chemical data from City drinking-water supply wells, the Mann-Kendall test was performed by well for the same subset of 10 parameters used in the investigation of variability. When the Mann-Kendall test indicated that an upward or downward trend in a particular water-quality parameter was significant (at the 0.05 level), the Kendall-Theil robust line was determined for the data to obtain a slope that could be used to estimate the magnitude of the trend over a given time period. Trend magnitudes indicated by the slope of the line were normalized to a period of 1 year.

For several wells, the combination of water-quality trends in a single well does not agree with what would be expected in terms of the necessity for electrical or mass balance in a sample. For example, if the concentration of a cation in water from a particular well has an upward trend, the necessity for electrical balance dictates that the concentration of an anion should also have upward trend. This expected trend does not always occur. Similarly, if the concentrations of both a cation and an anion increase in water from a particular well, the necessity for mass balance dictates that the dissolved-solids concentration also should increase. Again, this expected trend does not always occur. The failure of such agreement in all cases is likely due to the uncertainty that is inherent in both statistics and laboratory techniques. For this study, a significance level of 0.05 was chosen to determine when a temporal trend could be assumed to exist. This level of significance indicates a chance of 5 percent that a correlation will be assumed where one does not truly exist. Also, some temporal trends that truly do exist have been assumed not to exist because they did not meet the criteria of a p-value less than 0.05. Because of the nature of statistics, these errors would occur even if all data values reported by the laboratory were exactly correct and if the number of samples for each parameter for each well were the same. Therefore, because the number of samples for each parameter differs even for the same well and because laboratory error does exist, even more errors in the assigning of temporal trends exist than would occur for a "perfect" data set. Despite these uncertainties (which cannot be prevented), the statistics that can be obtained provide important information that can be useful in analyzing the response of the aquifer to changing stresses over time. Therefore, although the reader should be aware of these uncertainties, they will not be mentioned in any detail in the following discussions.

Table 5. Interquartile ranges and median values of selected parameters for City of Albuquerque drinking-water supply wells

[Data in bold are equal to or greater than the 10th largest interquartile range (IQR) of all wells for that parameter. mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; deg. C, degrees Celsius; nd, no data]

Well name	Dissolved solids (mg/L)			Calcium (mg/L)			Sodium (mg/L)			Bicarbonate (mg/L as $CaCO_3$)			Sulfate (mg/L)		
	IQR	Median	IQR as percentage of median	IQR	Median	IQR as percentage of median	IQR	Median	IQR as percentage of median	IQR	Median	IQR as percentage of median	IQR	Median	IQR as percentage of median
Western region:															
Atrisco 1	18	376	4.8	0.85	7.98	10.7	**10**	107	9.3	6	109	5.5	5	110	4.5
Gonzales 1	16	320	5.0	1.8	12.3	14.6	8.7	83.3	10.4	4	126	3.2	5.0	77.1	6.5
College 1	24	324	7.4	0.36	3.60	10.0	9.1	104	8.7	5	156	3.2	2.5	55.3	4.5
College 2	23	319	7.2	1.92	3.20	60.0	7.4	100	7.4	**13**	143	9.1	4.5	59.7	7.5
Leavitt 1	25	304	8.2	0.88	5.68	15.5	7.5	93.7	8.0	6	138	4.3	3.1	55.5	5.6
Leavitt 2	31	340	9.1	0.28	4.40	6.4	**10**	106	9.4	7	142	4.9	**15.0**	68.1	22.0
Leavitt 3	19	440	4.3	0.24	2.45	9.8	**11**	140	7.9	8	117	6.8	**10**	133	7.5
West Mesa 1	**33**	336	9.8	0.63	1.92	32.8	**13**	108	12.0	**12**	144	8.3	**18.4**	67.9	27.1
West Mesa 2	27	295	9.2	1.17	5.12	22.9	**17.5**	91.9	19.0	7	144	4.9	2.9	49.4	5.9
West Mesa 3	25	308	8.1	0.67	3.89	17.2	9.3	97.5	9.5	6	147	4.1	2.8	50.4	5.6
West Mesa 4	**44**	337	13.1	1.43	3.26	43.9	**17**	112	15.2	**22**	130	16.9	**29**	87.0	33.3
Minimum	*16*	*295*	*4.3*	*0.24*	*1.92*	*6.4*	*7.4*	*83.3*	*7.4*	*4*	*109*	*3.2*	*2.5*	*49.4*	*4.5*
Maximum	*44*	*440*	*13.1*	*1.92*	*12.3*	*60.0*	*17.5*	*140*	*19.0*	*22*	*156*	*16.9*	*29*	*133*	*33.3*
Median	*25*	*324*	*8.1*	*0.85*	*3.89*	*15.5*	*10.*	*104*	*9.4*	*7*	*142*	*4.9*	*5.0*	*67.9*	*6.5*
Central region:															
Atrisco 2	16	428	3.7	4.5	44.4	10.1	5.0	66.0	7.6	9	164	5.5	7	111	6.3
Atrisco 3	20	320	6.3	2.9	25.9	11.2	6.5	61.0	10.7	5	126	4.0	**8.3**	78.4	10.6
Atrisco 4	28	336	8.3	3.7	27.7	13.4	6.5	61.6	10.6	6	133	4.5	**9.8**	77.1	12.7
Burton 1	16	288	5.6	3.0	31.0	9.7	3.4	39.8	8.5	5	109	4.6	1.7	34.4	4.9
Burton 4	14	308	4.5	3.0	28.4	10.6	4.0	48.2	8.3	6	112	5.4	1.8	35.8	5.0
Duranes 1	28	409	6.8	**7.0**	41.2	17.0	**10.3**	67.8	15.2	**18**	152	11.8	**10**	115	8.7
Duranes 2	22	304	7.2	4.6	27.6	16.7	8.3	49.0	16.9	6	124	4.8	1.9	67.5	2.8
Duranes 3	12	356	3.4	5.9	39.5	14.9	**11.6**	54.2	21.4	8	148	5.4	5.9	88.2	6.7
Duranes 4	19	317	6.0	1.7	20.4	8.3	9.6	67.4	14.2	5	126	4.0	5.9	70.8	8.3
Duranes 5	14	312	4.5	2.7	23.7	11.4	8.6	60.7	14.2	5	128	3.9	2.8	67.7	4.1
Duranes 6	20	396	5.1	2.2	52.6	4.2	2.7	42.2	6.4	9	167	5.4	5.3	93.4	5.7
Duranes 7	22	300	7.3	2.9	32.4	9.0	**9.7**	46.3	21.0	4	126	3.2	**7.6**	69.0	11.0
Gonzales 2	16	308	5.2	2.2	22.2	9.9	7.2	62.1	11.6	4	129	3.1	4.3	63.5	6.8
Griegos 1	32	300	10.7	**8.1**	41.2	19.7	3.4	23.6	14.4	**11**	127	8.7	3.8	60.7	6.3
Griegos 2	**60**	359	16.7	5.0	47.0	10.6	4.6	34.3	13.4	**13**	159	8.2	6.9	79.2	8.7
Griegos 3	16	296	5.4	5.6	30.1	18.6	5.6	43.1	13.0	4	116	3.4	2.6	66.3	3.9
Griegos 4	22	274	8.0	6.4	29.4	21.8	3.8	36.0	10.6	7	127	5.5	2.3	45.3	5.1
Miles Road 1	27	305	8.9	3.5	34.9	10.0	7.3	41.0	17.8	6	107	5.6	5.0	39.0	12.8
San Jose 1	**48**	428	11.2	**9.1**	56.5	16.1	3.2	36.2	8.8	10	168	6.0	**16**	109	14.7
San Jose 2	16	304	5.3	3.0	27.2	11.0	5.8	46.3	12.5	4	108	3.7	3.2	53.8	5.9

Table 5. Interquartile ranges and median values of selected parameters for City of Albuquerque drinking-water supply wells--Continued

Well name	Dissolved solids (mg/L)			Calcium (mg/L)			Sodium (mg/L)			Bicarbonate (mg/L as $CaCO_3$)			Sulfate (mg/L)		
	IQR	Median	IQR as percentage of median	IQR	Median	IQR as percentage of median	IQR	Median	IQR as percentage of median	IQR	Median	IQR as percentage of median	IQR	Median	IQR as percentage of median
San Jose 3	18	310	5.8	2.1	17.6	11.9	6.1	65.4	9.3	4	114	3.5	2.8	69.3	4.0
Volcano Cliffs 1	18	280	6.4	2.5	20.0	12.5	8.5	52.8	16.1	9	120	7.5	1.5	48.9	3.1
Volcano Cliffs 2	20	272	7.4	2.7	21.0	12.9	5.4	48.8	11.1	7	117	6.0	2.9	45.8	6.3
Volcano Cliffs 3	21	284	7.4	2.0	16.1	12.4	7.1	61.5	11.5	6	123	4.9	2.7	47.7	5.7
Yale 2	32	292	11.0	5.0	37.1	13.5	5.4	33.1	16.3	6	107	5.6	6.1	40.1	15.2
Yale 3	25	343	7.3	2.9	44.3	6.5	8.0	38.6	20.7	7	123	5.7	5.0	67.1	7.5
Zamora 1	12	304	3.9	2.0	20.3	9.9	3.8	59.9	6.3	5	126	4.0	4.0	57.4	7.0
Minimum	*12*	*272*	*3.4*	*1.7*	*16.1*	*4.2*	*2.7*	*23.6*	*6.3*	*4*	*107*	*3.1*	*1.5*	*34.4*	*2.8*
Maximum	*60*	*428*	*16.7*	*9.1*	*56.5*	*21.8*	*11.6*	*67.8*	*21.4*	*18*	*168*	*11.8*	*16*	*115*	*15.2*
Median	*20*	*308*	*6.4*	*3.0*	*29.4*	*11.4*	*6.1*	*48.8*	*12.5*	*6*	*126*	*5.4*	*4.3*	*67.1*	*6.3*
East Mesa region:															
Burton 2	20	268	7.5	4.0	39.3	10.2	2.1	26.3	8.0	4	107	3.7	3.3	36.4	9.1
Burton 3	16	272	5.9	6.4	42.7	15.0	2.8	26.0	10.8	7	105	6.7	6.3	41.9	15.0
Burton 5	16	250	6.4	1.7	36.9	4.6	2.6	24.2	10.7	3	105	2.9	0.8	28.9	2.8
Charles Wells 1	16	225	7.1	2.9	38.1	7.6	3.2	31.4	10.2	5	118	4.2	1.5	31.3	4.8
Charles Wells 2	24	212	11.3	2.4	39.9	6.0	1.9	21.8	8.7	**11**	110	10.0	2.1	34.4	6.1
Charles Wells 3	20	203	9.9	3.0	39.4	7.6	1.4	19.7	7.1	7	107	6.5	2.2	30.7	7.2
Charles Wells 4	16	243	6.6	3.7	45.3	8.2	4.0	31.9	12.5	**11**	121	9.1	1.6	26.8	6.0
Charles Wells 5	28	224	12.5	3.4	40.5	8.4	1.3	24.2	5.4	3	105	2.9	2.4	28.9	8.3
Leyendecker 1	18	207	8.7	3.7	42.0	8.8	2.6	19.8	13.1	5	111	4.5	1.5	30.6	4.9
Leyendecker 2	24	210	11.4	5.5	42.2	13.0	1.8	22.7	7.9	4	113	3.5	2.3	32.7	7.0
Leyendecker 3	18	201	9.0	2.2	40.1	5.5	1.5	17.3	8.7	5	108	4.6	4.9	29.9	16.4
Leyendecker 4	19	224	8.5	2.5	42.9	5.8	2.7	23.7	11.4	6	121	5.0	3.0	33.9	8.8
Ridgecrest 4	26	243	10.7	5.6	45.7	12.3	2.9	26.4	11.0	8	110	7.3	2.6	26.3	9.9
Ridgecrest 5	12	236	5.1	5.2	41.4	12.6	2.6	24.4	10.7	4	108	3.7	2.3	26.6	8.6
Santa Barbara 1	21	223	9.4	2.8	32.0	8.8	3.0	26.3	11.4	7	108	6.5	3.1	33.4	9.3
Thomas 5	6	250	2.4	3.3	40.3	8.2	2.9	36.9	7.9	3	131	2.3	5.3	36.1	14.7
Thomas 7	12	258	4.7	2.7	42.7	6.3	2.6	35.8	7.3	3	127	2.4	5.6	34.5	16.2
Vol Andia 1	**48**	244	19.7	**8.5**	54.7	15.5	2.3	21.2	10.8	10	109	9.2	**25.1**	51.7	48.5
Vol Andia 2	26	192	13.5	4.5	38.8	11.6	2.1	17.6	11.9	2	100	2.2	2.2	29.5	7.5
Vol Andia 3	32	245	13.1	6.3	51.2	12.3	2.7	21.1	12.8	5	101	4.6	5.1	56.7	9.0
Vol Andia 4	**36**	204	17.6	5.6	43.0	13.0	2.1	16.9	12.4	5	107	4.7	4.0	35.6	11.2
Vol Andia 5	20	248	8.1	6.1	47.9	12.7	3.2	20.0	16.0	5	101	5.0	4.5	62.6	7.2
Vol Andia 6	24	205	11.7	5.8	40.9	14.2	1.9	17.7	10.7	8	108	7.4	5.2	36.7	14.2

Table 5. Interquartile ranges and median values of selected parameters for City of Albuquerque drinking-water supply wells--Continued

Well name	Dissolved solids (mg/L) IQR	Dissolved solids (mg/L) Median	Dissolved solids (mg/L) IQR as percentage of median	Calcium (mg/L) IQR	Calcium (mg/L) Median	Calcium (mg/L) IQR as percentage of median	Sodium (mg/L) IQR	Sodium (mg/L) Median	Sodium (mg/L) IQR as percentage of median	Bicarbonate (mg/L as $CaCO_3$) IQR	Bicarbonate (mg/L as $CaCO_3$) Median	Bicarbonate (mg/L as $CaCO_3$) IQR as percentage of median	Sulfate (mg/L) IQR	Sulfate (mg/L) Median	Sulfate (mg/L) IQR as percentage of median
Yale 1	14	256	5.5	4.8	38.3	12.5	3.7	26.0	14.2	6	106	5.7	4.5	38.1	11.8
Minimum	*6*	*192*	*2.4*	*1.7*	*32.0*	*4.6*	*1.3*	*16.9*	*5.4*	*2*	*100*	*2.2*	*0.8*	*26.3*	*2.8*
Maximum	*48*	*272*	*19.7*	*8.5*	*54.7*	*15.5*	*4.0*	*36.9*	*16.0*	*11*	*131*	*10.0*	*25.1*	*62.6*	*48.5*
Median	*20*	*231*	*8.8*	*3.9*	*41.2*	*9.5*	*2.6*	*24.0*	*10.8*	*5*	*108*	*4.7*	*3.1*	*33.7*	*8.9*
Northeast region:															
Coronado 1	20	361	5.5	2.1	30.2	7.0	7.5	71.5	10.5	5	118	4.2	2.1	40.5	5.2
Coronado 2	12	300	4.0	2.8	31.6	8.9	5.6	49.2	11.4	5	137	3.6	1.9	48.2	3.9
Love 8	31	276	11.2	2.9	49.8	5.8	2.7	33.7	8.0	3	113	2.7	3.4	25.7	13.2
Ponderosa 1	20	344	5.8	5.3	55.0	9.6	6.4	56.0	11.4	7	121	5.8	1.4	31.7	4.4
Ponderosa 3	28	380	7.4	**7.3**	58.1	12.6	5.6	54.6	10.3	5	132	3.8	2.1	35.1	6.0
Ponderosa 5	24	270	8.9	4.3	52.1	8.3	3.3	35.7	9.2	5	108	4.6	2.7	23.3	11.6
Ponderosa 6	13	384	3.4	5.7	48.8	11.7	6.6	65.1	10.1	5	137	3.6	2.2	36.7	6.0
Thomas 1	12	285	4.2	5.0	55.4	9.0	4.6	37.9	12.1	7	133	5.3	2.4	30.3	7.9
Thomas 2	19	287	6.6	**8.5**	52.0	16.3	4.8	40.7	11.8	7	130	5.4	1.7	26.7	6.4
Thomas 3	23	291	7.9	**7.1**	54.3	13.1	3.2	43.7	7.3	9	139	6.5	2.6	36.0	7.2
Thomas 4	**40**	315	12.7	2.4	60.1	4.0	5.3	52.0	10.2	8	140	5.7	3.4	30.0	11.3
Thomas 6	20	328	6.1	**10.7**	58.2	18.4	5.9	41.9	14.1	4	128	3.1	6.4	29.7	21.5
Thomas 8	32	368	8.7	**7.3**	69.6	10.5	4.2	39.5	10.6	6	118	5.1	2.5	28.4	8.8
Walker 1	26	268	9.7	**5.8**	47.	12.3	3.6	38.5	9.4	3	101	3.1	2.8	24.1	11.6
Walker 2	16	375	4.3	**6.7**	39.1	17.1	5.6	79.2	7.1	5	139	3.6	3.5	35.9	9.7
Webster 1	19	300	6.3	3.1	28.7	10.8	8.0	56.6	14.1	6	126	4.8	2.4	37.1	6.5
Webster 2	20	285	7.0	2.6	30.0	8.7	4.8	44.1	10.9	4	130	3.1	2.0	38.6	5.2
Minimum	*12*	*268*	*3.4*	*2.1*	*28.7*	*4.0*	*2.7*	*33.7*	*7.1*	*3*	*101*	*2.7*	*1.4*	*23.3*	*3.9*
Maximum	*40*	*384*	*12.7*	*10.7*	*69.6*	*18.4*	*8.0*	*79.2*	*14.1*	*9*	*140*	*6.5*	*6.4*	*48.2*	*21.5*
Median	*20*	*300*	*6.6*	*5.3*	*52.0*	*10.5*	*5.3*	*44.1*	*10.5*	*5*	*130*	*4.2*	*2.4*	*31.7*	*7.2*
Mountain Front region:															
Lomas 1	**40**	356	11.2	6.5	75.9	8.6	3.3	28.9	11.4	**14**	158	8.9	6.7	81.9	8.2
Lomas 5	17	215	7.9	3.4	28.8	11.8	4.0	39.6	10.1	5	124	4.0	1.6	31.7	5.0
Lomas 6	**42**	266	15.8	5.3	45.9	11.5	3.1	39.1	7.9	**11**	143	7.7	5.1	56.2	9.1
Love 1	16	190	8.4	6.1	31.1	19.6	3.5	32.4	10.8	10	112	8.9	2.1	24.4	8.6
Love 3	12	195	6.2	3.8	36.7	10.4	2.6	26.9	9.7	4	106	3.8	2.7	19.0	14.2
Love 4	20	235	8.5	5.8	46.5	12.5	2.8	27.6	10.1	5	112	4.5	0.9	21.2	4.2
Love 5	16	203	7.9	1.9	38.8	4.9	1.9	26.5	7.2	**12**	108	11.1	0.9	19.6	4.6
Love 6	24	168	14.3	1.7	24.4	7.0	2.2	33.1	6.6	4	108	3.7	0.9	16.8	5.4
Love 7	17	204	8.3	4.2	40.3	10.4	3.1	26.4	11.7	8	104	7.7	0.8	19.1	4.2

Table 5. Interquartile ranges and median values of selected parameters for City of Albuquerque drinking-water supply wells--Continued

Well name	Dissolved solids (mg/L)			Calcium (mg/L)			Sodium (mg/L)			Bicarbonate (mg/L as $CaCO_3$)			Sulfate (mg/L)		
	IQR	Median	IQR as percentage of median	IQR	Median	IQR as percentage of median	IQR	Median	IQR as percentage of median	IQR	Median	IQR as percentage of median	IQR	Median	IQR as percentage of median
Ponderosa 2	**34**	210	16.2	2.7	42.6	6.3	2.3	27.0	8.5	10	108	9.3	0.8	19.6	4.1
Ponderosa 4	32	224	14.3	3.7	42.0	8.8	4.2	35.0	12.0	6	110	5.5	1.3	19.0	6.8
Ridgecrest 1	24	265	9.1	**9.0**	52.4	17.2	2.3	29.0	7.9	**15**	146	10.3	5.9	51.8	11.4
Ridgecrest 2	25	198	12.6	2.3	33.6	6.8	2.2	27.7	7.9	3	100	3.3	2.6	19.8	13.1
Ridgecrest 3	26	210	12.4	5.0	39.2	12.8	3.6	26.1	13.8	5	107	4.7	0.9	22.1	4.1
Minimum	*12*	*168*	*6.2*	*1.7*	*24.4*	*4.9*	*1.9*	*26.1*	*6.6*	*3*	*100*	*3.3*	*0.8*	*16.8*	*4.1*
Maximum	*42*	*356*	*16.2*	*9.0*	*75.9*	*19.6*	*4.2*	*39.6*	*13.8*	*15*	*158*	*11.1*	*6.7*	*81.9*	*14.2*
Median	*24*	*210*	*10.1*	*4.0*	*39.8*	*10.4*	*3.0*	*28.3*	*9.9*	*7*	*109*	*6.6*	*1.5*	*20.5*	*6.1*
<u>All wells:</u>															
Minimum	*6*	*168*	*2.4*	*0.24*	*1.92*	*4.0*	*1.3*	*16.9*	*5.4*	*2*	*100*	*2.2*	*0.8*	*16.8*	*2.8*
Maximum	*60*	*440*	*19.7*	*10.7*	*75.9*	*60.0*	*17.5*	*140*	*21.4*	*22*	*168*	*16.9*	*29*	*133*	*48.5*
Median	*20*	*287*	*7.9*	*3.4*	*39.2*	*11.0*	*4.0*	*39.1*	*10.7*	*6*	*121*	*4.9*	*2.9*	*38.1*	*7.2*

Table 5. Interquartile ranges and median values of selected parameters for City of Albuquerque drinking-water supply wells--Continued

	Chloride (mg/L)			Silica (mg/L)			Arsenic (µg/L)			Field pH (standard units)			Temperature (deg. C)		
Well name	IQR	Median	IQR as percentage of median	IQR	Median	IQR as percentage of median	IQR	Median	IQR as percentage of median	IQR	Median	IQR as percentage of median	IQR	Median	IQR as percentage of median
Western region:															
Atrisco 1	2.8	19.8	14.1	4.9	46.9	10.4	3	22	13.6	0.26	8.77	3.0	0.4	31.5	1.3
Gonzales 1	1.01	9.93	10.2	7.8	50.6	15.4	3	23	13.0	0.13	8.26	1.6	0.7	23.7	3.0
College 1	0.92	5.52	16.7	3.6	28.7	12.5	**5**	49	10.2	0.28	8.65	3.2	0.6	28.0	2.1
College 2	0.84	6.24	13.5	3.4	30.1	11.3	**4**	33	12.1	0.37	8.84	4.2	**4.2**	31.0	13.5
Leavitt 1	1.3	11.8	11.0	4.2	31.3	13.4	**5**	38	13.2	0.30	8.59	3.5	0.8	23.4	3.4
Leavitt 2	2.7	18.8	14.4	2.8	29.8	9.4	**5**	34	14.7	0.24	8.70	2.8	**1.4**	23.9	5.9
Leavitt 3	1.9	31.6	6.0	3.6	38.6	9.3	3	35	8.6	0.20	9.00	2.2	0.6	33.4	1.9
West Mesa 1	0.92	6.32	14.6	7.2	36.2	19.9	**6**	27	22.2	0.28	8.99	3.1	**2.5**	29.5	8.5
West Mesa 2	1.51	7.27	20.8	1.9	32.4	5.9	**4**	40	10.0	0.28	8.60	3.3	0.3	25.0	1.2
West Mesa 3	0.77	8.32	9.3	2.5	29.4	8.5	**6**	40	15.0	0.24	8.70	2.8	**1.0**	25.2	4.0
West Mesa 4	4.9	14.8	33.1	4.6	35.8	12.8	**12**	36	33.3	**0.47**	8.88	5.3	**6.8**	29.8	22.8
Minimum	*0.77*	*5.52*	*6.0*	*1.9*	*28.7*	*5.9*	*3*	*22*	*8.6*	*0.13*	*8.26*	*1.6*	*0.3*	*23.4*	*1.2*
Maximum	*4.9*	*31.6*	*33.1*	*7.8*	*50.6*	*19.9*	*12*	*49*	*33.3*	*0.47*	*9.00*	*5.3*	*6.8*	*33.4*	*22.8*
Median	*1.3*	*9.93*	*14.1*	*3.6*	*32.4*	*11.3*	*5*	*35*	*13.2*	*0.28*	*8.70*	*3.1*	*0.8*	*28.0*	*3.4*
Central region:															
Atrisco 2	1.3	16.6	7.8	5.3	65.9	8.0	1	7	14.3	0.30	7.50	4.0	0.2	18.3	1.1
Atrisco 3	1.6	12.8	12.5	6.5	57.2	11.4	2	9	22.2	**0.41**	7.80	5.3	0.8	18.5	4.3
Atrisco 4	0.8	12.2	6.6	6.9	65.8	10.5	2	10	20.0	0.25	7.79	3.2	0.6	21.5	2.8
Burton 1	5.4	36.1	15.0	8.7	64.5	13.5	3	15	20.0	0.20	7.84	2.6	0.5	24.5	2.0
Burton 4	3.5	41.6	8.4	6.5	70.2	9.3	2	21	9.5	0.16	7.86	2.0	0.1	26.2	0.4
Duranes 1	2.0	17.5	11.4	**8.9**	66.0	13.5	**4**	15	26.7	0.27	7.52	3.6	0.6	20.3	2.7
Duranes 2	0.7	10.5	6.7	7.0	63.6	11.0	1	8	12.5	0.33	7.88	4.2	0.3	19.1	1.6
Duranes 3	1.2	12.7	9.4	5.3	62.4	8.5	1	6	16.7	0.21	7.67	2.7	0.3	19.0	1.6
Duranes 4	2.3	12.4	18.5	5.1	63.6	8.0	2	13	15.4	0.27	7.97	3.4	0.5	19.6	2.6
Duranes 5	1.3	12.2	10.7	6.5	63.0	10.3	2	10	20.0	0.22	7.90	2.8	0.3	20.4	1.5
Duranes 6	1.3	14.4	9.0	2.2	69.5	3.2	1	4	25.0	**0.41**	7.39	5.5	0.3	19.0	1.3
Duranes 7	0.8	10.7	7.5	4.8	59.4	8.1	2	8	25.0	0.24	7.77	3.1	0.8	17.7	4.5
Gonzales 2	0.5	10.0	4.6	8.3	68.8	12.1	3	13	23.1	0.17	7.89	2.2	0.5	25.3	2.0
Griegos 1	1.5	12.1	12.4	**11.6**	64.4	18.0	1	6	16.7	0.34	7.56	4.5	0.5	17.9	2.8
Griegos 2	1.7	12.4	13.7	**12.2**	68.5	17.8	2	5	40.0	**0.44**	7.57	5.8	0.9	18.5	4.6
Griegos 3	0.9	11.6	7.8	**9.2**	63.7	14.4	1	6	16.7	0.37	7.89	4.7	0.4	18.3	2.2
Griegos 4	0.85	9.38	9.1	**13.7**	64.7	21.2	2	13	15.4	**0.57**	7.70	7.4	0.5	18.6	2.7
Miles Road 1	2.4	38.6	6.2	**9.7**	71.0	13.7	2	16	12.5	0.31	7.88	3.9	0.7	25.5	2.7
San Jose 1	5.7	16.3	35.0	6.3	69.4	9.1	1	6	16.7	0.25	7.34	3.4	0.6	19.0	3.2
San Jose 2	1.7	24.8	6.9	6.7	71.1	9.4	3	20	15.0	0.21	7.90	2.7	0.2	25.8	0.8

Table 5. Interquartile ranges and median values of selected parameters for City of Albuquerque drinking-water supply wells--Continued

	Chloride (mg/L)			Silica (mg/L)			Arsenic (µg/L)			Field pH (standard units)			Temperature (deg. C)		
Well name	**IQR**	**Median**	**IQR as percentage of median**	**IQR**	**Median**	**IQR as percentage of median**	**IQR**	**Median**	**IQR as percentage of median**	**IQR**	**Median**	**IQR as percentage of median**	**IQR**	**Median**	**IQR as percentage of median**
San Jose 3	1.0	14.7	6.8	6.9	66.7	10.3	**5**	33	15.2	0.29	8.09	3.6	0.4	24.3	1.6
Volcano Cliffs 1	0.81	8.3	9.8	7.1	68.9	10.3	2	14	14.3	0.33	8.00	4.1	0.8	23.9	3.3
Volcano Cliffs 2	0.88	7.8	11.3	5.3	70.3	7.5	1	11	9.1	0.26	8.00	3.3	0.4	24.0	1.7
Volcano Cliffs 3	0.79	7.37	10.7	5.3	65.2	8.1	2	15	13.3	0.21	8.08	2.6	0.5	24.4	2.0
Yale 2	2.3	34.8	6.6	8.6	66.5	12.9	1	11	9.1	0.32	7.70	4.2	0.5	23.1	2.2
Yale 3	4.1	29.5	13.9	**12.2**	73.2	16.7	2	13	15.4	0.34	7.63	4.5	0.4	24.7	1.6
Zamora 1	0.50	9.22	5.4	6.3	70.8	8.9	1	14	7.1	0.16	7.92	2.0	0.3	24.2	1.2
Minimum	*0.46*	*7.37*	*4.6*	*2.2*	*57.2*	*3.2*	*1*	*4*	*7.1*	*0.16*	*7.34*	*2.0*	*0.1*	*17.7*	*0.4*
Maximum	*5.7*	*41.6*	*35.0*	*13.7*	*73.2*	*21.2*	*5*	*33*	*40.0*	*0.57*	*8.09*	*7.4*	*0.9*	*26.2*	*4.6*
Median	*1.3*	*12.4*	*9.1*	*6.9*	*66.0*	*10.3*	*2*	*11*	*15.4*	*0.27*	*7.84*	*3.6*	*0.5*	*20.4*	*2.0*
East Mesa region:															
Burton 2	3.6	31.1	11.6	4.3	51.5	8.3	0	4	0.0	0.26	7.70	3.4	0.1	20.9	0.5
Burton 3	3.0	30.5	9.8	4.6	49.7	9.3	1	5	20.0	**0.39**	7.70	5.1	0.4	20.6	1.9
Burton 5	1.8	31.4	5.7	5.6	51.6	10.9	1	6	16.7	0.11	7.77	1.4	0.2	22.3	0.9
Charles Wells 1	5.2	18.0	28.9	3.8	26.8	14.2	0	2	0.0	**0.42**	7.80	5.4	0.5	19.6	2.6
Charles Wells 2	1.0	11.5	8.7	**9.1**	29.0	31.4	0	2	0.0	0.25	7.76	3.2	**0.9**	19.0	4.7
Charles Wells 3	1.29	9.49	13.6	3.4	33.1	10.3	1	2	50.0	0.34	7.83	4.3	0.2	18.4	1.1
Charles Wells 4	4.1	32.8	12.5	1.5	26.6	5.6	0	2	0.0	0.24	7.72	3.1	0.2	20.6	1.0
Charles Wells 5	6.4	19.9	32.2	5.8	40.4	14.4	1	4	25.0	0.23	7.75	3.0	0.2	19.4	1.0
Leyendecker 1	0.9	10.0	9.2	2.6	34.0	7.6	1	5	20.0	0.23	7.73	3.0	0.2	18.8	1.1
Leyendecker 2	0.9	10.2	9.3	4.3	32.0	13.4	0	3	0.0	0.29	7.71	3.8	0.2	18.9	1.1
Leyendecker 3	0.86	7.97	10.8	3.4	31.6	10.8	1	6	16.7	0.25	7.84	3.2	0.3	18.0	1.7
Leyendecker 4	1.3	11.1	11.7	3.4	32.9	10.3	2	5	40.0	0.29	7.67	3.8	0.2	19.2	1.0
Ridgecrest 4	3.3	38.3	8.6	6.3	34.0	18.5	1	3	33.3	0.26	7.72	3.4	0.5	21.7	2.3
Ridgecrest 5	2.7	32.6	8.3	5.1	37.1	13.7	2	5	40.0	0.18	7.72	2.3	0.3	22.3	1.3
Santa Barbara 1	1.65	8.66	19.1	3.4	47.4	7.2	1	11	9.1	0.27	7.84	3.4	0.2	19.6	1.0
Thomas 5	2.5	18.1	13.8	3.0	36.2	8.3	2	9	22.2	0.32	7.56	4.2	0.6	21.3	2.8
Thomas 7	5.5	26.9	20.4	5.1	35.0	14.6	2	6	33.3	0.26	7.63	3.4	**0.9**	21.3	4.2
Vol Andia 1	3.4	13.5	25.2	3.2	31.6	10.1	1	7	14.3	0.27	7.85	3.4	0.3	17.2	1.7
Vol Andia 2	0.77	9.65	8.0	2.8	33.0	8.5	1	6	16.7	0.19	7.85	2.4	0.1	17.5	0.6
Vol Andia 3	3.6	17.8	20.2	3.4	37.3	9.1	1	7	14.3	0.22	7.86	2.8	0.1	18.0	0.6
Vol Andia 4	1.49	9.49	15.7	2.3	30.9	7.4	1	8	12.5	0.31	7.88	3.9	0.2	17.0	1.2
Vol Andia 5	1.9	15.3	12.4	6.9	34.1	20.2	2	7	28.6	0.22	7.88	2.8	0.3	17.6	1.7
Vol Andia 6	0.99	8.77	11.3	2.2	30.9	7.1	1	8	12.5	0.24	7.82	3.1	0.5	16.7	3.0

Table 5. Interquartile ranges and median values of selected parameters for City of Albuquerque drinking-water supply wells--Continued

	Chloride (mg/L)			Silica (mg/L)			Arsenic (µg/L)			Field pH (standard units)			Temperature (deg. C)		
Well name	**IQR**	**Median**	**IQR as percentage of median**	**IQR**	**Median**	**IQR as percentage of median**	**IQR**	**Median**	**IQR as percentage of median**	**IQR**	**Median**	**IQR as percentage of median**	**IQR**	**Median**	**IQR as percentage of median**
Yale 1	2.4	20.9	11.5	7.9	57.4	13.8	1	7	14.3	0.31	7.79	4.0	0.2	21.3	0.9
Minimum	*0.77*	*7.97*	*5.7*	*1.5*	*26.6*	*5.6*	*0*	*2*	*0.0*	*0.11*	*7.56*	*1.4*	*0.1*	*16.7*	*0.5*
Maximum	*6.4*	*38.3*	*32.2*	*9.1*	*57.4*	*31.4*	*2*	*11*	*50.0*	*0.42*	*7.88*	*5.4*	*0.9*	*22.3*	*4.7*
Median	*2.15*	*16.6*	*11.6*	*3.6*	*34.0*	*10.3*	*1*	*6*	*16.7*	*0.26*	*7.77*	*3.4*	*0.2*	*19.3*	*1.1*
Northeast region:															
Coronado 1	**7.4**	75.6	9.8	6.7	59.3	11.3	3	28	10.7	0.22	7.88	2.8	0.2	22.8	0.9
Coronado 2	1.9	24.6	7.7	6.2	52.3	11.9	3	16	18.8	0.17	7.76	2.2	0.2	20.8	1.0
Love 8	**10.2**	49.0	20.8	**11.4**	33.9	33.6	0	2	0.0	0.37	7.67	4.8	0.3	21.7	1.4
Ponderosa 1	**7.1**	83.6	8.5	3.8	34.6	11.0	3	18	16.7	0.26	7.63	3.4	**0.9**	26.8	3.4
Ponderosa 3	**7.1**	90.2	7.9	4.2	39.7	10.6	**4**	23	17.4	0.25	7.56	3.3	0.3	28.1	1.1
Ponderosa 5	5.4	55.8	9.7	2.5	31.1	8.0	**4**	25	16.0	0.22	7.69	2.9	0.2	25.8	0.8
Ponderosa 6	5.2	87.8	5.9	4.5	42.9	10.5	**6**	34	17.6	0.20	7.59	2.6	0.5	27.8	1.8
Thomas 1	4.7	46.2	10.2	4.1	30.7	13.4	0	2	0.0	**0.44**	7.60	5.8	0.5	22.2	2.3
Thomas 2	7.0	53.6	13.1	3.6	30.9	11.7	0	2	0.0	**0.39**	7.62	5.1	0.3	24.5	1.2
Thomas 3	2.4	41.9	5.7	nd	36.4	nd	2	6	33.3	0.35	7.58	4.6	0.7	21.4	3.3
Thomas 4	**12.8**	64.0	20.0	1.7	34.6	4.9	0	2	0.0	**0.41**	7.61	5.4	0.7	24.0	2.9
Thomas 6	**8.9**	68.1	13.1	4.2	34.6	12.1	2	6	33.3	0.19	7.55	2.5	**1.0**	23.4	4.3
Thomas 8	5.0	86.2	5.8	3.3	32.0	10.3	**4**	13	30.8	0.17	7.58	2.2	**0.9**	26.0	3.5
Walker 1	**8.9**	56.9	15.6	3.8	31.5	12.1	**3**	21	14.3	0.2	7.67	2.6	0.3	26.9	0.9
Walker 2	5.7	83.7	6.8	4.6	41.6	11.1	**6**	36	16.7	0.19	7.70	2.5	0.3	28.8	1.0
Webster 1	5.5	40.1	13.7	5.1	55.2	9.2	**4**	35	11.4	0.23	7.79	3.0	0.4	22.2	1.8
Webster 2	4.7	25.2	18.7	6.0	61.8	9.7	3	27	11.1	0.23	7.80	2.9	0.4	21.2	1.9
Minimum	*1.9*	*24.6*	*5.7*	*1.7*	*30.7*	*4.9*	*0*	*2*	*0.0*	*0.17*	*7.55*	*2.2*	*0.2*	*20.8*	*0.8*
Maximum	*12.8*	*90.2*	*20.8*	*11.4*	*61.8*	*33.6*	*6*	*36*	*33.3*	*0.44*	*7.88*	*5.8*	*1.0*	*28.8*	*4.3*
Median	*5.7*	*56.9*	*9.8*	*4.2*	*34.6*	*11.0*	*3*	*18*	*16.0*	*0.23*	*7.63*	*2.9*	*0.4*	*24.0*	*1.8*
Mountain Front region:															
Lomas 1	**9.2**	20.6	44.7	2.3	22.7	10.1	0	2	0.0	0.27	7.42	3.6	0.3	22.0	1.4
Lomas 5	0.78	6.47	12.1	4.3	26.6	16.2	1	4	25.0	0.23	7.90	2.9	0.7	26.7	2.6
Lomas 6	1.05	9.58	11.0	2.2	25.8	8.5	0	2	0.0	0.27	7.68	3.5	0.2	25.0	0.8
Love 1	1.42	6.67	21.3	4.9	26.7	18.4	0	2	0.0	0.17	7.77	2.2	0.5	23.7	2.1
Love 3	2.3	17.3	13.3	3.8	30.2	12.6	0	2	0.0	0.27	7.80	3.5	0.2	23.2	0.9
Love 4	4.1	35.0	11.7	5.3	29.8	17.8	0	2	0.0	0.22	7.70	2.9	0.4	22.7	1.8
Love 5	3.8	22.1	17.2	3.9	28.1	13.9	0	2	0.0	0.28	7.75	3.6	0.4	22.6	1.8
Love 6	1.33	4.79	27.8	3.0	29.1	10.3	0	2	0.0	0.34	7.91	4.3	0.3	25.3	1.2
Love 7	3.0	25.0	12.0	3.8	30.6	12.4	1	4	25.0	0.31	7.71	4.0	0.2	24.0	0.8

Table 5. Interquartile ranges and median values of selected parameters for City of Albuquerque drinking-water supply wells--Concluded

	Chloride (mg/L)			Silica (mg/L)			Arsenic (µg/L)			Field pH (standard units)			Temperature (deg. C)		
Well name	**IQR**	**Median**	**IQR as percentage of median**	**IQR**	**Median**	**IQR as percentage of median**	**IQR**	**Median**	**IQR as percentage of median**	**IQR**	**Median**	**IQR as percentage of median**	**IQR**	**Median**	**IQR as percentage of median**
Ponderosa 2	**14.8**	23.5	63.0	3.5	30.4	11.5	1	6	16.7	0.27	7.75	3.5	0.6	25.4	2.4
Ponderosa 4	**20.1**	33.3	60.4	3.4	30.1	11.3	2	14	14.3	0.31	7.75	4.0	0.4	26.3	1.5
Ridgecrest 1	1.8	11.4	15.8	3.3	27.0	12.2	0	2	0.0	**0.42**	7.53	5.6	0.5	22.7	2.2
Ridgecrest 2	3.1	27.0	11.5	3.0	28.0	10.7	1	2	50.0	0.37	7.84	4.7	0.4	23.8	1.7
Ridgecrest 3	1.9	24.7	7.7	3.9	30.3	12.9	1	3	33.3	0.32	7.80	4.1	0.3	22.6	1.3
Minimum	*0.78*	*4.79*	*7.7*	*2.2*	*22.7*	*8.5*	*0*	*2*	*0.0*	*0.17*	*7.42*	*2.2*	*0.2*	*22.0*	*0.8*
Maximum	*20.1*	*35.0*	*63.0*	*5.3*	*30.6*	*18.4*	*2*	*14*	*50.0*	*0.42*	*7.91*	*5.6*	*0.7*	*26.7*	*2.6*
Median	*2.65*	*21.4*	*14.5*	*3.7*	*28.6*	*12.3*	*0*	*2*	*0.0*	*0.28*	*7.75*	*3.6*	*0.4*	*23.8*	*1.6*
All wells:															
Minimum	*0.46*	*4.79*	*4.6*	*1.5*	*22.7*	*3.2*	*0*	*2*	*0.0*	*0.11*	*7.34*	*1.4*	*0.1*	*16.7*	*0.4*
Maximum	*20.1*	*90.2*	*63.0*	*13.7*	*73.2*	*33.6*	*12*	*49*	*50.0*	*0.57*	*9.00*	*7.4*	*6.8*	*33.4*	*22.8*
Median	*2.0*	*17.5*	*11.5*	*4.6*	*36.2*	*10.9*	*2*	*8*	*15.0*	*0.27*	*7.77*	*3.4*	*0.4*	*22.6*	*1.8*

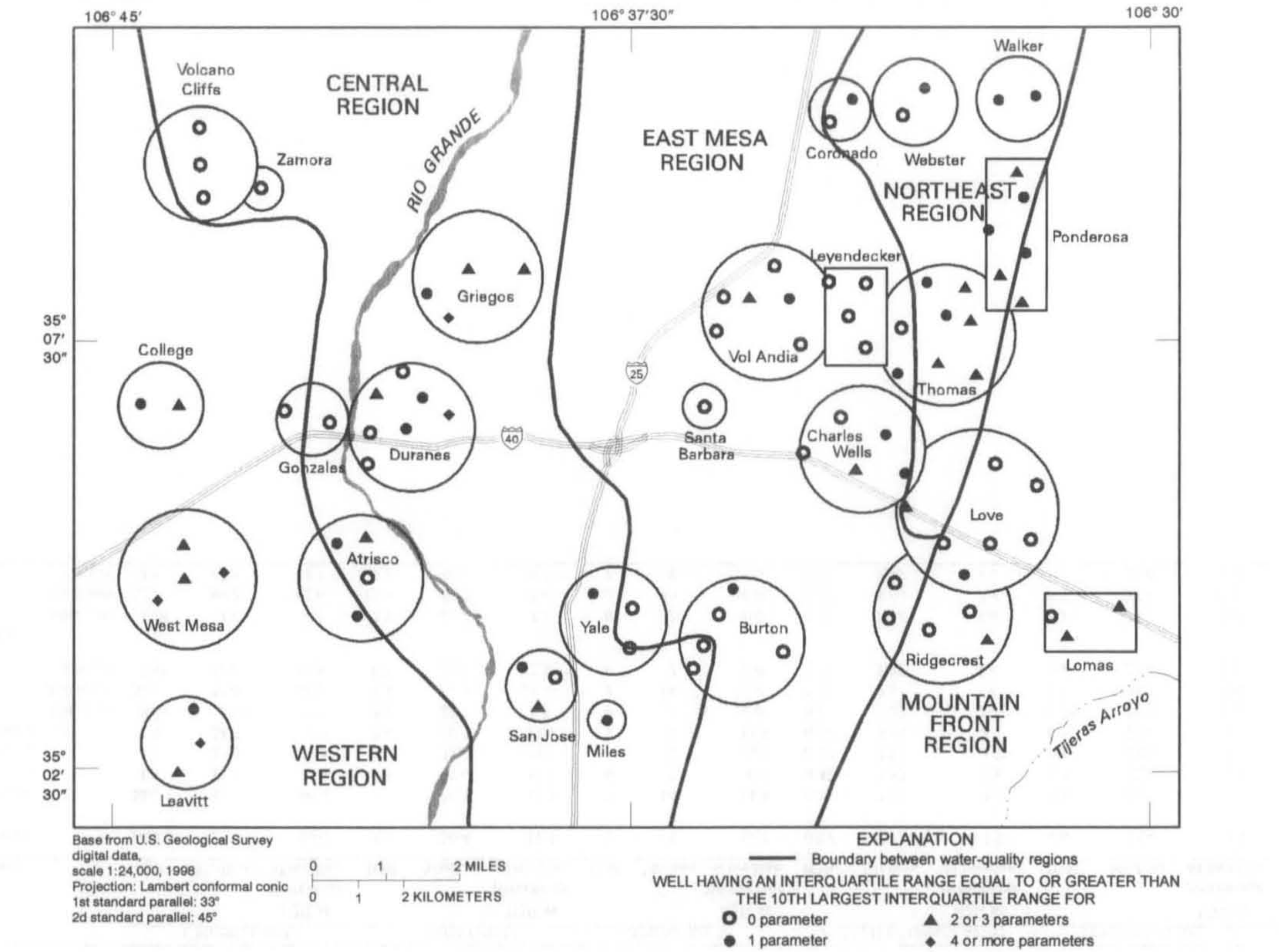


Figure 40. Number of parameters for which City of Albuquerque drinking-water supply wells have large interquartile ranges.

Trends with time are quite common among the City drinking-water supply wells for several of the parameters investigated. Trends in dissolved-solids concentration occur in 57 of 93 wells; 56 of these trends are upward. Estimated magnitudes of these trends over a 1-year period vary from 1.6 to 9.8 mg/L, with a median of 3.2 mg/L (table 6). Trends in chloride and sulfate concentrations and water temperature also occur in 50 or more wells. Thirty-five of the chloride trends are upward and 22 are downward; magnitudes vary from less than 0.1 to 3.7 mg/L per year, with a median of 0.44 mg/L per year. Forty-four of the sulfate trends are upward and 12 are downward; magnitudes over a year vary from less than 0.1 to 4.6 mg/L, with a median of 0.70 mg/L. Eleven of the trends in water temperature are upward and 39 are downward; magnitudes over a year vary from 0.02 to 0.46 degree Celsius, with a median of 0.07 degree Celsius. Trends in field pH occur in 41 wells; only 1 well has an upward trend. Magnitudes over a year vary from 0.01 to 0.10 pH unit, with a median of 0.03 unit.

Trends in bicarbonate concentration occur in 28 wells; 12 of the trends are upward and 16 are downward. Magnitudes of the trends over a year vary from 0.32 to 2.1 mg/L, with a median of 0.84 mg/L.

Trends in calcium concentration occur in 27 wells; 21 of these trends are downward and 6 are upward. Magnitudes of calcium trends vary from less than 0.1 to 2.2 mg/L per year, with a median of 0.51 mg/L per year (table 6).

Trends in arsenic concentration occur in 26 wells; 6 of the trends are upward and 20 are downward. Magnitudes of the trends vary from less than 0.1 to 2.6 µg/L per year, with a median of 0.31 µg/L per year.

Sodium and silica concentrations show the fewest trends among the wells. Trends in sodium concentration with time occur in 15 wells; 14 trends are upward and 1 is downward. Magnitudes over a year vary from about 0.3 to 2.9 mg/L, with a median of about 0.6 mg/L. Trends in silica concentration occur in five wells; all five trends are upward. Magnitudes over a year vary from 0.60 to 2.8 mg/L, with a median of about 1.0 mg/L.

Overall, the median magnitudes of temporal trends in most parameters are quite small. In particular, all median magnitudes for the major constituents (chloride, sulfate, bicarbonate, calcium, sodium, and silica) are less than 1.0 mg/L over a 1-year period. A few wells, though, do show yearly trends of more than 2.0 mg/L in major constituents. Among these constituents, about 62 percent of trends are upward and 38 percent are downward.

To determine which wells and areas generally have the greatest number of temporal trends in water quality, the number of constituents for which each well had a statistically significant trend was determined and plotted on a map (fig. 41). Only two wells (Burton 5 and Love 1) show no trends in any of the 10 parameters investigated; 10 wells (Burton 4, Duranes 3, Griegos 2, Love 4, Ponderosa 3, Ridgecrest 2, 3, and 5, and Vol Andia 4 and 5) show a time trend for only one parameter. The Atrisco, Leavitt, Lomas, Miles, Ponderosa, Ridgecrest, San Jose, Vol Andia, Volcano Cliffs, Webster, and West Mesa well fields all include wells that show temporal trends in more than five parameters. Overall, the Western region has the largest number of temporal trends per well, whereas the East Mesa region has the smallest.

Correlations Between Water Quality and Monthly Pumpage Volumes

To test for any correlations between water quality and pumping volumes per unit time in City drinking-water supply wells, Kendall's tau was determined by well for each of the same 10 parameters investigated for variability and temporal trends. For each well, total volumes of water pumped per month, in acre-feet, were used for the investigation. Daily and weekly pumpage totals for individual wells currently cannot be obtained digitally. Although such data would probably provide a better representation of water-quality changes with changes in pumping volume, monthly totals should enable discernment of at least the stronger relations. For this study, pumpage during the 1-month period prior to collection of an individual sample was assumed to have the greatest influence on water quality observed in that sample. To assign monthly pumpage volumes to the chemical data, sample dates were categorized into the first, second, or third 10 days of a month. If the sample was collected in the first 10 days of the month, the previous month's pumpage total was assigned to the sample; if the sample was collected in the second 10 days of the month, the average of the previous and current months' pumpage totals was assigned; and if the sample was collected in the last 10 days of the month, the current month's pumpage total was assigned.

Table 6. Magnitudes, directions, and tau values of temporal trends for selected parameters in City of Albuquerque drinking-water supply wells

[Magnitudes are for a 1-year period, calculated from the slope of the Kendall-Theil line. Where no data are given, no significant trend existed. Selected statistics for trend magnitudes and tau values by parameter are given for water-quality regions and for all wells. mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; deg. C, degrees Celsius; Mag., magnitude of trend; Dir., direction of trend]

	Dissolved solids (mg/L)			Calcium (mg/L)			Sodium (mg/L)			Bicarbonate (mg/L as $CaCO_3$)			Sulfate (mg/L)		
Well name	Mag.	Dir.	Tau	Mag.	Dir.	Tau	Mag.	Dir.	Tau	Mag.	Dir.	Tau	Mag.	Dir.	Tau
Western region:															
Atrisco 1				0.12	up	0.22									
Gonzales 1													1.7	up	0.29
College 1	3.1	up	0.30	0.06	down	0.26									
College 2	1.9	up	0.21	0.14	down	0.29							0.25	up	0.14
Leavitt 1	2.9	up	0.27	0.13	down	0.23				0.49	down	0.15	0.40	up	0.28
Leavitt 2				0.48	down	0.27							1.2	down	0.13
Leavitt 3				0.07	down	0.43							0.67	down	0.18
West Mesa 1				0.10	down	0.32				0.80	down	0.18	0.41	down	0.16
West Mesa 2													1.6	down	0.34
West Mesa 3	2.4	up	0.25	0.15	down	0.45				0.70	down	0.25	0.58	up	0.29
West Mesa 4	5.0	up	0.33	0.19	down	0.36	2.9	up	0.35	2.1	down	0.28	1.3	up	0.27
Minimum	*1.9*		*0.21*	*0.06*		*0.22*	*2.9*		*0.35*	*0.49*		*0.15*	*0.25*		*0.13*
Maximum	*5.0*		*0.33*	*0.48*		*0.45*	*2.9*		*0.35*	*2.1*		*0.28*	*1.7*		*0.34*
Median	*2.9*		*0.27*	*0.13*		*0.29*	*2.9*		*0.35*	*0.75*		*0.22*	*0.67*		*0.27*
Number of trends	*5*		*5*	*9*		*9*	*1*		*1*	*4*		*4*	*9*		*9*
Upward trends		*5*			*1*			*1*			*0*			*5*	
Downward trends		*0*			*8*			*0*			*4*			*4*	
Central region:															
Atrisco 2	1.8	up	0.21				0.99	up	0.23	1.4	up	0.39			
Atrisco 3	1.6	up	0.18	0.41	down	0.26									
Atrisco 4	5.1	up	0.51	0.76	up	0.38				0.74	up	0.30	1.7	up	0.63
Burton 1	3.0	up	0.41										0.17	down	0.31
Burton 4															
Duranes 1	6.6	up	0.47							1.5	up	0.26	2.1	up	0.52
Duranes 2										0.83	down	0.28			
Duranes 3															
Duranes 4	2.8	up	0.29												
Duranes 5													0.43	down	0.31

Table 6. Magnitudes, directions, and tau values of temporal trends for selected parameters in City of Albuquerque drinking-water supply wells--Continued

	Dissolved solids (mg/L)			Calcium (mg/L)			Sodium (mg/L)			Bicarbonate (mg/L as $CaCO_3$)			Sulfate (mg/L)		
Well name	**Mag.**	**Dir.**	**Tau**	**Mag.**	**Dir.**	**Tau**	**Mag.**	**Dir.**	**Tau**	**Mag.**	**Dir.**	**Tau**	**Mag.**	**Dir.**	**Tau**
Duranes 6															
Duranes 7													1.1	down	0.39
Gonzales 2	2.2	up	0.29										1.3	up	0.47
Griegos 1	6.4	up	0.47										0.46	up	0.28
Griegos 2													2.3	down	0.31
Griegos 3															
Griegos 4	3.7	up	0.42												
Miles Road 1	4.5	up	0.50				0.88	up	0.29				0.97	up	0.50
San Jose 1	7.6	down	0.64	2.2	down	0.54				1.4	down	0.42	2.7	down	0.56
San Jose 2	1.9	up	0.29										0.78	up	0.51
San Jose 3	1.8	up	0.25										0.67	up	0.43
Volcano Cliffs 1	1.9	up	0.28				1.1	up	0.26						
Volcano Cliffs 2	2.2	up	0.28	0.24	down	0.22							0.42	up	0.37
Volcano Cliffs 3	3.0	up	0.37	0.40	down	0.38							0.31	up	0.31
Yale 2	5.0	up	0.69										1.2	up	0.54
Yale 3	2.8	up	0.31							1.2	up	0.38			
Zamora 1	2.4	up	0.21	0.58	down	0.27							1.9	up	0.74
Minimum	*1.6*		*0.18*	*0.24*		*0.22*	*0.88*		*0.23*	*0.74*		*0.26*	*0.17*		*0.28*
Maximum	*7.6*		*0.69*	*2.2*		*0.54*	*1.1*		*0.29*	*1.5*		*0.42*	*2.7*		*0.74*
Median	*2.8*		*0.31*	*0.50*		*0.33*	*0.99*		*0.26*	*1.3*		*0.34*	*1.0*		*0.45*
Number of trends	*19*		*19*	*6*		*6*	*3*		*3*	*6*		*6*	*16*		*16*
Upward trends		*18*			*1*			*3*			*4*			*11*	
Downward trends		*1*			*5*			*0*			*2*			*5*	
East Mesa region:															
Burton 2	4.9	up	0.60				0.46	up	0.33	0.89	up	0.35	1.1	up	0.61
Burton 3													0.66	down	0.33
Burton 5															
Charles Wells 1															
Charles Wells 2	3.0	up	0.42							0.84	down	0.27			

Table 6. Magnitudes, directions, and tau values of temporal trends for selected parameters in City of Albuquerque drinking-water supply wells--Continued

	Dissolved solids (mg/L)			Calcium (mg/L)			Sodium (mg/L)			Bicarbonate (mg/L as $CaCO_3$)			Sulfate (mg/L)		
Well name	**Mag.**	**Dir.**	**Tau**	**Mag.**	**Dir.**	**Tau**	**Mag.**	**Dir.**	**Tau**	**Mag.**	**Dir.**	**Tau**	**Mag.**	**Dir.**	**Tau**
Charles Wells 3	3.3	up	0.40							0.75	down	0.33			
Charles Wells 4	2.0	up	0.28							0.81	down	0.33			
Charles Wells 5				0.71	up	0.40							0.89	up	0.56
Leyendecker 1										0.48	down	0.25			
Leyendecker 2	2.2	up	0.26												
Leyendecker 3	3.1	up	0.44										0.43	up	0.28
Leyendecker 4	3.1	up	0.43												
Ridgecrest 4	4.5	up	0.41							0.67	down	0.33	0.27	down	0.41
Ridgecrest 5													0.76	up	0.47
Santa Barbara 1	2.3	up	0.30										0.47	up	0.35
Thomas 5													1.1	up	0.57
Thomas 7													1.4	up	0.59
Vol Andia 1	9.8	up	0.61	2.1	up	0.58							4.6	up	0.74
Vol Andia 2							0.27	down	0.34				0.46	up	0.40
Vol Andia 3	5.9	up	0.52										1.3	up	0.43
Vol Andia 4	3.6	up	0.31												
Vol Andia 5															
Vol Andia 6	5.9	up	0.53							1.2	up	0.50	0.85	up	0.39
Yale 1	3.2	up	0.43										1.0	up	0.41
Minimum	*2.0*		*0.26*	*0.71*		*0.40*	*0.27*		*0.33*	*0.48*		*0.25*	*0.27*		*0.28*
Maximum	*9.8*		*0.61*	*2.1*		*0.58*	*0.46*		*0.34*	*1.2*		*0.50*	*4.6*		*0.74*
Median	*3.3*		*0.43*	*1.41*		*0.49*	*0.37*		*0.34*	*0.81*		*0.33*	*0.87*		*0.42*
Number of trends	*14*		*14*	*2*		*2*	*2*		*2*	*7*		*7*	*14*		*14*
Upward trends		*14*			*2*			*1*			*2*			*12*	
Downward trends		*0*			*0*			*1*			*5*			*2*	
Northeast region:															
Coronado 1													0.41	up	0.31
Coronado 2				0.98	down	0.39	0.83	up	0.22				0.54	up	0.33
Love 8							0.56	up	0.41				0.85	up	0.63
Ponderosa 1	1.8	up	0.22	0.73	down	0.22				0.50	up	0.20	0.18	up	0.29

Table 6. Magnitudes, directions, and tau values of temporal trends for selected parameters in City of Albuquerque drinking-water supply wells--Continued

	Dissolved solids (mg/L)			Calcium (mg/L)			Sodium (mg/L)			Bicarbonate (mg/L as $CaCO_3$)			Sulfate (mg/L)		
Well name	**Mag.**	**Dir.**	**Tau**	**Mag.**	**Dir.**	**Tau**	**Mag.**	**Dir.**	**Tau**	**Mag.**	**Dir.**	**Tau**	**Mag.**	**Dir.**	**Tau**
Ponderosa 3				1.1	down	0.25									
Ponderosa 5	4.3	up	0.46				0.50	up	0.25	0.62	up	0.26	0.46	up	0.48
Ponderosa 6				0.91	down	0.25							0.19	up	0.19
Thomas 1	3.2	up	0.36												
Thomas 2															
Thomas 3	4.3	up	0.33	0.69	down	0.51									
Thomas 4	6.9	up	0.48							1.1	up	0.33	0.58	up	0.37
Thomas 6													1.2	up	0.49
Thomas 8															
Walker 1	5.0	up	0.51				0.38	up	0.19				0.45	up	0.46
Walker 2				1.0	down	0.30							0.28	up	0.15
Webster 1	2.3	up	0.26	0.58	down	0.32	1.0	up	0.22	0.32	up	0.13			
Webster 2	2.3	up	0.28	0.51	down	0.37							0.14	up	0.13
Minimum	*1.8*		*0.22*	*0.51*		*0.22*	*0.38*		*0.19*	*0.32*		*0.13*	*0.14*		*0.13*
Maximum	*6.9*		*0.51*	*1.1*		*0.51*	*1.0*		*0.41*	*1.1*		*0.33*	*1.2*		*0.63*
Median	*3.8*		*0.35*	*0.82*		*0.31*	*0.56*		*0.22*	*0.56*		*0.23*	*0.45*		*0.33*
Number of trends	*8*		*8*	*8*		*8*	*5*		*5*	*4*		*4*	*11*		*11*
Upward trends		*8*			*0*			*5*			*4*			*11*	
Downward trends		*0*			*8*			*0*			*0*			*0*	
Mountain Front region:															
Lomas 1	8.5	up	0.60							1.8	down	0.47	1.7	up	0.50
Lomas 5	3.8	up	0.34							0.72	up	0.32			
Lomas 6	6.5	up	0.66							1.1	up	0.29	0.74	up	0.28
Love 1															
Love 3							0.48	up	0.34	0.94	down	0.33			
Love 4	5.4	up	0.42												
Love 5	3.5	up	0.35	0.49	up	0.35	0.31	up	0.32	0.71	down	0.31			
Love 6	3.0	up	0.32										0.08	down	0.31
Love 7	2.9	up	0.49												
Ponderosa 2	5.1	up	0.62				0.36	up	0.31	0.96	down	0.44	0.07	up	0.24

Table 6. Magnitudes, directions, and tau values of temporal trends for selected parameters in City of Albuquerque drinking-water supply wells--Continued

	Dissolved solids (mg/L)			Calcium (mg/L)			Sodium (mg/L)			Bicarbonate (mg/L as $CaCO_3$)			Sulfate (mg/L)		
Well name	**Mag.**	**Dir.**	**Tau**	**Mag.**	**Dir.**	**Tau**	**Mag.**	**Dir.**	**Tau**	**Mag.**	**Dir.**	**Tau**	**Mag.**	**Dir.**	**Tau**
Ponderosa 4	7.5	up	0.71	0.76	up	0.30	0.70	up	0.25	0.91	down	0.35	0.09	up	0.20
Ridgecrest 1	4.3	up	0.29										0.85	up	0.32
Ridgecrest 2															
Ridgecrest 3	4.6	up	0.42												
Minimum	*2.9*		*0.29*	*0.49*		*0.30*	*0.31*		*0.25*	*0.71*		*0.29*	*0.07*		*0.20*
Maximum	*8.5*		*0.71*	*0.76*		*0.35*	*0.70*		*0.34*	*1.8*		*0.47*	*1.7*		*0.50*
Median	*4.6*		*0.42*	*0.63*		*0.33*	*0.42*		*0.32*	*0.94*		*0.33*	*0.42*		*0.30*
Number of trends	*11*		*11*	*2*		*2*	*4*		*4*	*7*		*7*	*6*		*6*
Upward trends		*11*			*2*			*4*			*2*			*5*	
Downward trends		*0*			*0*			*0*			*5*			*1*	
<u>**All wells:**</u>															
Minimum	*1.6*		*0.18*	*0.06*		*0.22*	*0.27*		*0.19*	*0.32*		*0.13*	*0.07*		*0.13*
Maximum	*9.8*		*0.71*	*2.2*		*0.58*	*2.9*		*0.41*	*2.1*		*0.50*	*4.6*		*0.74*
Median	*3.2*		*0.37*	*0.51*		*0.32*	*0.56*		*0.29*	*0.84*		*0.32*	*0.70*		*0.36*
Number of trends	*57*		*57*	*27*		*27*	*15*		*15*	*28*		*28*	*56*		*56*
Upward trends		*56*			*6*			*14*			*12*			*44*	
Downward trends		*1*			*21*			*1*			*16*			*12*	

Table 6. Magnitudes, directions, and tau values of temporal trends for selected parameters in City of Albuquerque drinking-water supply wells--Continued

Well name	Chloride (mg/L)			Silica (mg/L)			Arsenic (µg/L)			Field pH (standard units)			Temperature (deg. C)		
	Mag.	Dir.	Tau	Mag.	Dir.	Tau	Mag.	Dir.	Tau	Mag.	Dir.	Tau	Mag.	Dir.	Tau
Western region:															
Atrisco 1	0.50	down	0.52										0.03	down	0.21
Gonzales 1	0.54	up	0.55										0.20	down	0.42
College 1							0.34	down	0.17	0.02	down	0.20	0.04	down	0.23
College 2							0.25	down	0.15				0.12	up	0.15
Leavitt 1													0.04	up	0.13
Leavitt 2	0.21	down	0.15				0.79	down	0.43	0.02	down	0.20	0.13	down	0.24
Leavitt 3	0.24	down	0.33												
West Mesa 1	0.11	down	0.32										0.20	up	0.24
West Mesa 2	0.20	up	0.20				0.50	up	0.19						
West Mesa 3	0.06	up	0.17	0.60	up	0.28	0.65	down	0.28	0.01	up	0.15	0.14	up	0.32
West Mesa 4	0.49	up	0.38	0.64	up	0.20	0.69	up	0.18				0.31	up	0.33
Minimum	*0.06*		*0.15*	*0.60*		*0.20*	*0.25*		*0.15*	*0.01*		*0.15*	*0.03*		*0.13*
Maximum	*0.54*		*0.55*	*0.64*		*0.28*	*0.79*		*0.43*	*0.02*		*0.20*	*0.31*		*0.42*
Median	*0.23*		*0.33*	*0.62*		*0.24*	*0.58*		*0.19*	*0.02*		*0.20*	*0.13*		*0.24*
Number of trends	*8*		*8*	*2*		*2*	*6*		*6*	*3*		*3*	*9*		*9*
Upward trends		*4*			*2*			*2*			*1*			*5*	
Downward trends		*4*			*0*			*4*			*2*			*4*	
Central region:															
Atrisco 2	0.10	up	0.18				0.12	down	0.38				0.02	down	0.40
Atrisco 3	0.16	down	0.25				0.19	down	0.28				0.06	down	0.26
Atrisco 4	0.11	up	0.27				0.21	down	0.32				0.10	down	0.67
Burton 1	0.87	up	0.51							0.02	down	0.25			
Burton 4	0.52	up	0.38												
Duranes 1										0.04	down	0.38	0.08	down	0.42
Duranes 2							0.09	down	0.31				0.05	down	0.40
Duranes 3													0.09	down	0.51
Duranes 4	0.38	down	0.50				0.36	down	0.36				0.09	down	0.76
Duranes 5	0.17	down	0.27										0.08	down	0.63

Table 6. Magnitudes, directions, and tau values of temporal trends for selected parameters in City of Albuquerque drinking-water supply wells--Continued

Well name	Chloride (mg/L)			Silica (mg/L)			Arsenic (µg/L)			Field pH (standard units)			Temperature (deg. C)		
	Mag.	Dir.	Tau	Mag.	Dir.	Tau	Mag.	Dir.	Tau	Mag.	Dir.	Tau	Mag.	Dir.	Tau
Duranes 6							0.06	down	0.35				0.09	down	0.51
Duranes 7							0.14	down	0.30	0.04	down	0.32	0.16	down	0.48
Gonzales 2															
Griegos 1							0.09	down	0.28				0.20	down	0.56
Griegos 2															
Griegos 3										0.06	down	0.40	0.17	down	0.58
Griegos 4										0.08	down	0.41	0.12	down	0.80
Miles Road 1	0.41	up	0.40	2.8	up	0.36	0.28	up	0.29	0.02	down	0.33	0.09	up	0.36
San Jose 1	0.94	down	0.55										0.13	down	0.71
San Jose 2	0.28	down	0.42				0.14	down	0.15	0.02	down	0.16	0.03	down	0.31
San Jose 3	0.21	down	0.39				0.49	down	0.25	0.03	down	0.26	0.08	down	0.43
Volcano Cliffs 1	0.06	down	0.21							0.03	down	0.29	0.04	down	0.36
Volcano Cliffs 2	0.08	down	0.26							0.02	down	0.31	0.04	down	0.32
Volcano Cliffs 3							0.20	up	0.23	0.02	down	0.28	0.03	down	0.18
Yale 2	0.27	up	0.24							0.04	down	0.29			
Yale 3	0.44	down	0.31	2.7	up	0.43				0.06	down	0.48			
Zamora 1										0.03	down	0.21			
Minimum	*0.06*		*0.18*	*2.70*		*0.36*	*0.06*		*0.15*	*0.02*		*0.16*	*0.02*		*0.18*
Maximum	*0.94*		*0.55*	*2.80*		*0.43*	*0.49*		*0.38*	*0.08*		*0.48*	*0.20*		*0.80*
Median	*0.27*		*0.31*	*2.75*		*0.40*	*0.17*		*0.30*	*0.03*		*0.30*	*0.08*		*0.46*
Number of trends	*15*		*15*	*2*		*2*	*12*		*12*	*14*		*14*	*20*		*20*
Upward trends		*6*			*2*			*2*			*0*			*1*	
Downward trends		*9*			*0*			*10*			*14*			*19*	
East Mesa region:															
Burton 2	1.1	up	0.34												
Burton 3	0.34	down	0.28												
Burton 5															
Charles Wells 1	0.92	down	0.62										0.07	down	0.46
Charles Wells 2										0.03	down	0.37	0.16	down	0.66

Table 6. Magnitudes, directions, and tau values of temporal trends for selected parameters in City of Albuquerque drinking-water supply wells--Continued

Well name	Chloride (mg/L) Mag.	Chloride Dir.	Chloride Tau	Silica (mg/L) Mag.	Silica Dir.	Silica Tau	Arsenic (µg/L) Mag.	Arsenic Dir.	Arsenic Tau	Field pH (standard units) Mag.	Field pH Dir.	Field pH Tau	Temperature (deg. C) Mag.	Temperature Dir.	Temperature Tau
Charles Wells 3	0.18	up	0.31												
Charles Wells 4													0.05	down	0.50
Charles Wells 5	2.2	up	0.69												
Leyendecker 1													0.06	down	0.41
Leyendecker 2	0.13	up	0.32							0.05	down	0.38	0.05	down	0.55
Leyendecker 3	0.10	up	0.27							0.04	down	0.30	0.09	down	0.46
Leyendecker 4	0.17	up	0.30							0.03	down	0.24	0.06	down	0.42
Ridgecrest 4	0.50	up	0.30							0.04	down	0.31	0.05	down	0.30
Ridgecrest 5															
Santa Barbara 1	0.21	up	0.38							0.03	down	0.32			
Thomas 5	0.73	down	0.54												
Thomas 7	1.4	down	0.65												
Vol Andia 1	0.59	up	0.53				0.13	down	0.34	0.04	down	0.38			
Vol Andia 2													0.02	down	0.35
Vol Andia 3	0.84	up	0.54												
Vol Andia 4															
Vol Andia 5	0.38	down	0.46												
Vol Andia 6	0.16	up	0.49				0.04	down	0.31	0.03	down	0.27	0.07	down	0.43
Yale 1	0.50	up	0.67							0.04	down	0.38			
Minimum	*0.10*		*0.27*				*0.04*		*0.31*	*0.03*		*0.24*	*0.02*		*0.30*
Maximum	*2.2*		*0.69*				*0.13*		*0.34*	*0.05*		*0.38*	*0.16*		*0.66*
Median	*0.50*		*0.46*				*0.09*		*0.33*	*0.04*		*0.32*	*0.06*		*0.45*
Number of trends	*17*		*17*				*2*		*2*	*9*		*9*	*10*		*10*
Upward trends		*12*						*0*			*0*			*0*	
Downward trends		*5*						*2*			*9*			*10*	
Northeast region:															
Coronado 1	1.1	down	0.34				0.34	down	0.23				0.02	down	0.31
Coronado 2	0.64	down	0.50				0.47	up	0.21						
Love 8															
Ponderosa 1										0.03	down	0.41	0.07	up	0.23

Table 6. Magnitudes, directions, and tau values of temporal trends for selected parameters in City of Albuquerque drinking-water supply wells--Continued

Well name	Chloride (mg/L)			Silica (mg/L)			Arsenic (µg/L)			Field pH (standard units)			Temperature (deg. C)		
	Mag.	Dir.	Tau	Mag.	Dir.	Tau	Mag.	Dir.	Tau	Mag.	Dir.	Tau	Mag.	Dir.	Tau
Ponderosa 3															
Ponderosa 5	0.78	up	0.36				0.45	down	0.24	0.03	down	0.32			
Ponderosa 6							0.39	up	0.16						
Thomas 1	0.61	up	0.32							0.03	down	0.26			
Thomas 2	0.95	down	0.34	0.99	up	0.56									
Thomas 3										0.10	down	0.61	0.09	down	0.32
Thomas 4										0.06	down	0.52			
Thomas 6	2.8	down	0.58												
Thomas 8	1.8	up	0.31				2.6	down	0.46				0.46	down	0.40
Walker 1	2.0	up	0.61				0.34	down	0.20						
Walker 2															
Webster 1										0.01	down	0.13	0.07	up	0.44
Webster 2	0.54	up	0.31							0.02	down	0.21	0.02	down	0.15
Minimum	*0.54*		*0.31*	*0.99*		*0.56*	*0.34*		*0.16*	*0.01*		*0.13*	*0.02*		*0.15*
Maximum	*2.8*		*0.61*	*0.99*		*0.56*	*2.6*		*0.46*	*0.10*		*0.61*	*0.46*		*0.44*
Median	*0.95*		*0.34*	*0.99*		*0.56*	*0.42*		*0.22*	*0.03*		*0.32*	*0.07*		*0.32*
Number of trends	*9*		*9*	*1*		*1*	*6*		*6*	*7*		*7*	*6*		*6*
Upward trends		*5*			*1*			*2*			*0*			*2*	
Downward trends		*4*			*0*			*4*			*7*			*4*	
Mountain Front region:															
Lomas 1	2.1	up	0.75							0.03	down	0.34	0.05	up	0.46
Lomas 5										0.02	down	0.33			
Lomas 6	0.13	up	0.30							0.03	down	0.37	0.05	down	0.41
Love 1															
Love 3	0.42	up	0.38							0.04	down	0.30			
Love 4															
Love 5	0.74	up	0.44												
Love 6	0.14	up	0.29												
Love 7	0.42	up	0.40												
Ponderosa 2	2.3	up	0.71							0.04	down	0.52	0.08	up	0.37

Table 6. Magnitudes, directions, and tau values of temporal trends for selected parameters in City of Albuquerque drinking-water supply wells--Concluded

	Chloride (mg/L)			Silica (mg/L)			Arsenic (µg/L)			Field pH (standard units)			Temperature (deg. C)		
Well name	**Mag.**	**Dir.**	**Tau**	**Mag.**	**Dir.**	**Tau**	**Mag.**	**Dir.**	**Tau**	**Mag.**	**Dir.**	**Tau**	**Mag.**	**Dir.**	**Tau**
Ponderosa 4	3.7	up	0.77							0.04	down	0.37	0.03	up	0.20
Ridgecrest 1										0.07	down	0.47	0.04	down	0.26
Ridgecrest 2										0.05	down	0.40			
Ridgecrest 3															
Minimum	*0.13*		*0.29*							*0.02*		*0.30*	*0.03*		*0.20*
Maximum	*3.7*		*0.77*							*0.07*		*0.52*	*0.08*		*0.46*
Median	*0.58*		*0.42*							*0.04*		*0.37*	*0.05*		*0.37*
Number of trends	*8*		*8*							*8*		*8*	*5*		*5*
Upward trends		*8*									*0*			*3*	
Downward trends		*0*									*8*			*2*	
All wells:															
Minimum	*0.06*		*0.15*	*0.60*		*0.20*	*0.04*		*0.15*	*0.01*		*0.13*	*0.02*		*0.13*
Maximum	*3.7*		*0.77*	*2.8*		*0.56*	*2.6*		*0.46*	*0.10*		*0.61*	*0.46*		*0.80*
Median	*0.44*		*0.38*	*0.99*		*0.36*	*0.31*		*0.28*	*0.03*		*0.32*	*0.07*		*0.40*
Number of trends	*57*		*57*	*5*		*5*	*26*		*26*	*41*		*41*	*50*		*50*
Upward trends		*35*			*5*			*6*			*1*			*11*	
Downward trends		*22*			*0*			*20*			*40*			*39*	

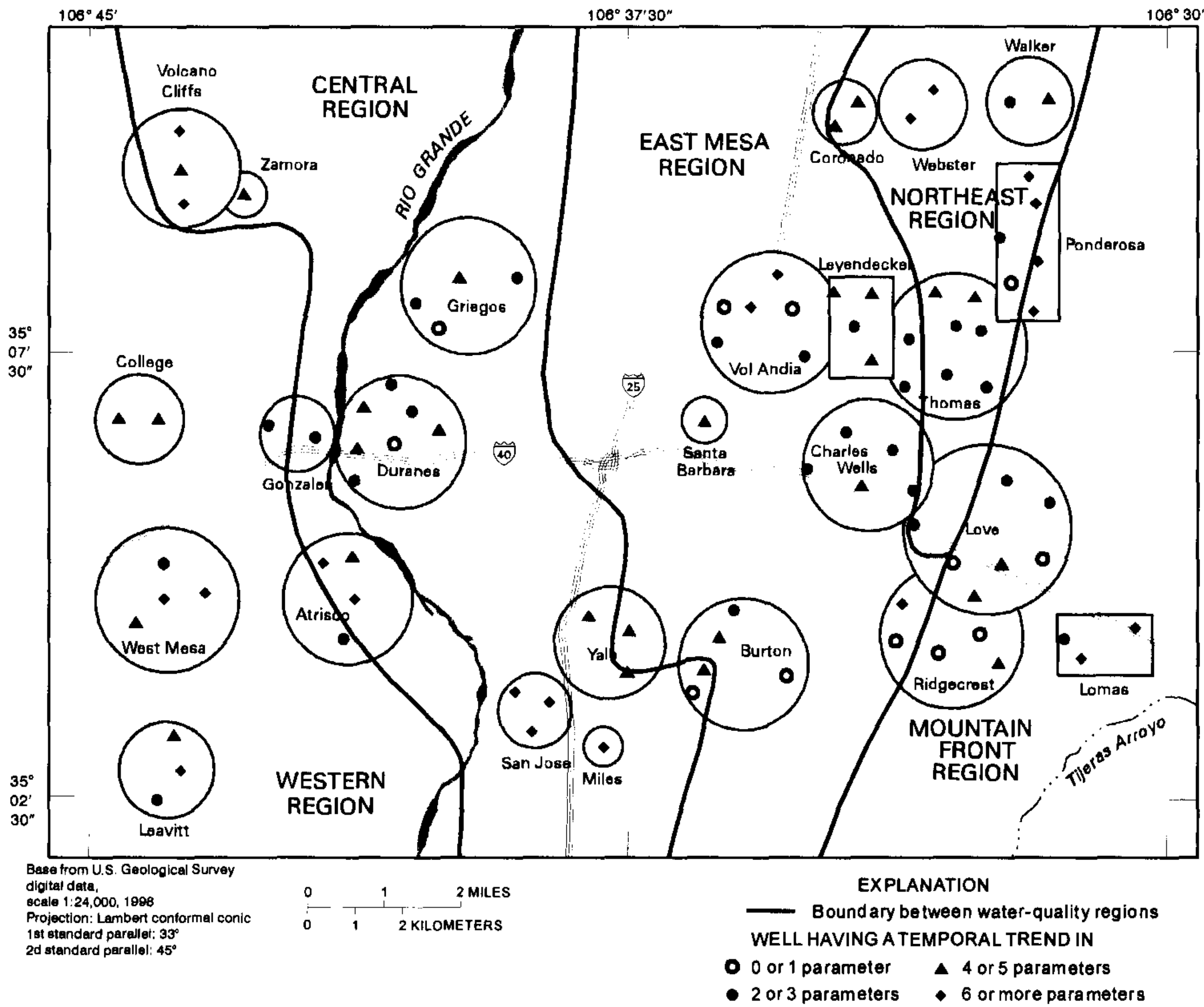


Figure 41. Number of parameters for which City of Albuquerque drinking-water supply wells have temporal trends.

For each parameter, about one-third or fewer of all wells show correlations with monthly pumpage volume. Correlations between dissolved-solids concentration and monthly pumpage volume occur in 29 wells (table 7). Eight of the correlations are positive (that is, dissolved-solids concentration increases with increasing monthly pumpage volume and decreases with decreasing monthly pumpage volume) and 21 are negative (dissolved-solids concentration decreases with increasing monthly pumpage volume and increases with decreasing monthly pumpage volume). For chloride, correlations occur in 32 wells; 10 are positive and 22 are negative. Sulfate has correlations in 29 wells; 17 are positive and 12 are negative. Bicarbonate has correlations in 25 wells; 11 are positive and 14 are negative. For calcium, correlations occur in 20 wells; 11 are positive and 9 are negative. Sodium has correlations in 14 wells; 5 are positive and 9 are negative. Silica has correlations in 10 wells; 4 are positive and 6 are negative. For arsenic, correlations occur in 25 wells; 7 are positive and 18 are negative. Field pH has correlations in 19 wells; all 19 correlations are positive. Water temperature has correlations in 26 wells; 19 are positive and 7 are negative.

To determine which wells and areas generally have the most correlations between water-quality parameters and monthly pumpage volumes, the number of parameters for which each well showed a correlation was determined and plotted on a map (fig. 42). Thirty-six wells scattered across the study area show correlations between one or no water-quality parameters and monthly pumpage volumes. Ten wells, clustered in the far northeast and far southwest parts of the study area, show correlations between six or more parameters and monthly pumpage volume. Overall, the Western and Northeast regions have the most correlations per well, whereas the Central region has the least.

Implications of Variation in Water Quality from Individual Wells

The areas in which water quality in individual wells most commonly varies, in addition to the manner in which such variation occurs, should provide information about how the aquifer is responding to pumping stresses. The implications of the statistical tests conducted to quantify variation and its relation to time and monthly pumpage are discussed by water-quality region. Although this discussion is detailed, it does not attempt to explain the variability in all wells. Emphasis is placed on groups of wells showing variability, trends, and (or) correlations that appear consistent with a single known process, such as a change in the contribution of water from different water-quality regions or different depths of the aquifer. The body of data available for this study does not always have the resolution necessary to determine the most likely source of variability in each well, however. Even when implications regarding the exact source of variability are unclear, the available data can be used to reach conclusions about the extent to which the aquifer is responding to pumping stresses and whether responses are similar across broad areas.

Western Region

Most drinking-water supply wells in the Western region show large variability in the parameters examined. Of the 11 wells in the region, 7 show large variability in two or more parameters and an additional 3 show large variability in one parameter. All the wells show trends in at least three parameters with time, and two wells show trends in nine parameters (table 8). Eight wells show correlations between at least three parameters and monthly pumpage volume, and two wells show correlations for nine parameters (table 8). The parameters that show large variability most commonly among these wells are arsenic (eight wells) and sodium (six wells). All 10 parameters show temporal trends in at least one well, but the parameters that most commonly show trends are sulfate (nine wells), calcium (nine wells), water temperature (nine wells), chloride (eight wells), and arsenic (six wells). None of these parameters trend in the same direction in all wells, which indicates that the aquifer is responding differently to pumping stresses at these wells. The observation that most wells in the Western region show correlations between multiple parameters and monthly pumpage volumes implies that local pumping stresses could be the most important factor causing variation in water quality in individual wells. Differences in the amount of water pumped from a well per unit time likely change the distribution of hydraulic head adjacent to the well, causing the distribution of water contributed to the well from different depths of the aquifer to change. The parameters for which these wells show correlations with monthly pumpage volume, and the directions of those correlations, generally are not consistent among these wells.

Table 7. Sign and tau of correlations between selected parameters and monthly pumpage volumes for City of Albuquerque drinking-water supply wells

[Where no data are given, no significant correlation existed. Selected statistics for tau values by parameter are given for each water-quality region and for all wells. neg., negative correlation; pos., positive correlation]

	Dissolved solids		Calcium		Sodium		Bicarbonate		Sulfate		Chloride		Silica		Arsenic		Field pH		Temperature	
Well name	Sign	Tau	Sign	Tau	Sign	Tau	Sign	Tau	Sign	Tau	Sign	Tau	Sign	Tau	Sign	Tau	Sign	Tau	Sign	Tau
Western region:																				
Atrisco 1			neg.	0.19																
Gonzales 1					pos.	0.25														
College 1	neg.	0.28													pos.	0.14	pos.	0.20	pos.	0.31
College 2			neg.	0.51	pos.	0.17	neg.	0.16	pos.	0.33			neg.	0.21			pos.	0.13	pos.	0.34
Leavitt 1	pos.	0.20	neg.	0.36			neg.	0.35	pos.	0.27	neg.	0.16	pos.	0.35					pos.	0.30
Leavitt 2	pos.	0.26							pos.	0.41	pos.	0.18	neg.	0.24	pos.	0.17			pos.	0.41
Leavitt 3					neg.	0.27			pos.	0.18			neg.	0.19						
West Mesa 1	neg.	0.14	neg.	0.55	neg.	0.27	neg.	0.34	neg.	0.33			pos.	0.45	pos.	0.32	pos.	0.30	pos.	0.41
West Mesa 2							neg.	0.30												
West Mesa 3			neg.	0.40			neg.	0.39	pos.	0.25			pos.	0.19	neg.	0.33	pos.	0.17	pos.	0.30
West Mesa 4	pos.	0.39	neg.	0.38			neg.	0.50	pos.	0.40	pos.	0.46	pos.	0.21	pos.	0.46	pos.	0.52	pos.	0.59
Minimum		*0.14*		*0.19*		*0.17*		*0.16*		*0.18*		*0.16*		*0.19*		*0.14*		*0.13*		*0.30*
Maximum		*0.39*		*0.55*		*0.27*		*0.50*		*0.41*		*0.46*		*0.45*		*0.46*		*0.52*		*0.59*
Median		*0.26*		*0.39*		*0.26*		*0.35*		*0.33*		*0.18*		*0.21*		*0.32*		*0.20*		*0.34*
Number of correlations		*5*		*6*		*4*		*6*		*7*		*3*		*7*		*5*		*5*		*7*
Positive correlations	*3*		*0*		*2*		*0*		*6*		*2*		*4*		*4*		*5*		*7*	
Negative correlations	*2*		*6*		*2*		*6*		*1*		*1*		*3*		*1*		*0*		*0*	
Central region:																				
Atrisco 2																			pos.	0.35
Atrisco 3					pos.	0.29			pos.	0.31	pos.	0.22								
Atrisco 4			neg.	0.31					neg.	0.32					pos.	0.19			pos.	0.36
Burton 1																				
Burton 4	neg.	0.29													neg.	0.31			neg.	0.28
Duranes 1	neg.	0.28							neg.	0.28										
Duranes 2							pos.	0.38	pos.	0.38										
Duranes 3																				
Duranes 4							neg.	0.32												
Duranes 5																				
Duranes 6																				
Duranes 7																				
Gonzales 2	neg.	0.29																		
Griegos 1																			pos.	0.32
Griegos 2									pos.	0.34										

Table 7. Sign and tau of correlations between selected parameters and monthly pumpage volumes for City of Albuquerque drinking-water supply wells--Continued

	Dissolved solids		Calcium		Sodium		Bicarbonate		Sulfate		Chloride		Silica		Arsenic		Field pH		Temperature	
Well name	**Sign**	**Tau**	**Sign**	**Tau**	**Sign**	**Tau**	**Sign**	**Tau**	**Sign**	**Tau**	**Sign**	**Tau**	**Sign**	**Tau**	**Sign**	**Tau**	**Sign**	**Tau**	**Sign**	**Tau**
Griegos 3																	pos.	0.42		
Griegos 4																			pos.	0.35
Miles Road 1																				
San Jose 1	pos.	0.30	pos.	0.27			pos.	0.18			pos.	0.19							pos.	0.29
San Jose 2							neg.	0.23												
San Jose 3																				
Volcano Cliffs 1							pos.	0.24												
Volcano Cliffs 2									neg.	0.19					pos.	0.17			pos.	0.19
Volcano Cliffs 3																				
Yale 2	neg.	0.28							neg.	0.27	neg.	0.42					pos.	0.26		
Yale 3																				
Zamora 1																				
Minimum		*0.28*		*0.27*		*0.29*		*0.18*		*0.19*		*0.19*				*0.17*		*0.26*		*0.19*
Maximum		*0.30*		*0.31*		*0.29*		*0.38*		*0.38*		*0.42*				*0.31*		*0.42*		*0.36*
Median		*0.29*		*0.29*		*0.29*		*0.24*		*0.31*		*0.22*				*0.19*		*0.34*		*0.32*
Number of correlations		*5*		*2*		*1*		*5*		*7*		*3*				*3*		*2*		*7*
Positive correlations	*1*		*1*		*1*		*3*		*3*		*2*				*2*		*2*		*6*	
Negative correlations	*4*		*1*		*0*		*2*		*4*		*1*				*1*		*0*		*1*	
East Mesa region:																				
Burton 2							neg.	0.48			neg.	0.43								
Burton 3																	pos.	0.27		
Burton 5	neg.	0.39													neg.	0.39				
Charles Wells 1			neg.	0.39					pos.	0.32	pos.	0.36							pos.	0.44
Charles Wells 2																				
Charles Wells 3							pos.	0.33	pos.	0.33									pos.	0.42
Charles Wells 4	pos.	0.26					pos.	0.27	pos.	0.29										
Charles Wells 5					neg.	0.36			neg.	0.39	neg.	0.41			neg.	0.42				
Leyendecker 1																				
Leyendecker 2																				
Leyendecker 3							neg.	0.28												
Leyendecker 4									pos.	0.29										
Ridgecrest 4							pos.	0.26			neg.	0.36								
Ridgecrest 5													neg.	0.61	neg.	0.45				
Santa Barbara 1			pos.	0.38			neg.	0.23											neg.	0.25

Table 7. Sign and tau of correlations between selected parameters and monthly pumpage volumes for City of Albuquerque drinking-water supply wells--Continued

Well name	Dissolved solids		Calcium		Sodium		Bicarbonate		Sulfate		Chloride		Silica		Arsenic		Field pH		Temperature	
	Sign	Tau	Sign	Tau	Sign	Tau	Sign	Tau	Sign	Tau	Sign	Tau	Sign	Tau	Sign	Tau	Sign	Tau	Sign	Tau
Thomas 5							neg.	0.38							neg.	0.38				
Thomas 7															neg.	0.59				
Vol Andia 1							neg.	0.38					neg.	0.55						
Vol Andia 2																	pos.	0.34		
Vol Andia 3			pos.	0.41															pos.	0.34
Vol Andia 4			pos.	0.33	pos.	0.37					pos.	0.33					pos.	0.34	pos.	0.28
Vol Andia 5									pos.	0.45	pos.	0.28								
Vol Andia 6			neg.	0.33																
Yale 1											neg.	0.40					pos.	0.43		
Minimum		*0.26*		*0.33*		*0.36*		*0.23*		*0.29*		*0.28*		*0.55*		*0.38*		*0.27*		*0.25*
Maximum		*0.39*		*0.41*		*0.37*		*0.48*		*0.45*		*0.43*		*0.61*		*0.59*		*0.43*		*0.44*
Median		*0.33*		*0.38*		*0.37*		*0.31*		*0.33*		*0.36*		*0.58*		*0.42*		*0.34*		*0.34*
Number of correlations		*2*		*5*		*2*		*8*		*6*		*7*		*2*		*5*		*4*		*5*
Positive correlations	*1*		*3*		*1*		*3*		*5*		*3*		*0*		*0*		*4*		*4*	
Negative correlations	*1*		*2*		*1*		*5*		*1*		*4*		*2*		*5*		*0*		*1*	
Northeast region:																				
Coronado 1			pos.	0.16	pos.	0.16					pos.	0.20			pos.	0.16	pos.	0.14		
Coronado 2																				
Love 8	neg.	0.46									neg.	0.54	neg.	0.67	neg.	0.60				
Ponderosa 1	neg.	0.23															pos.	0.17	neg.	0.39
Ponderosa 3	pos.	0.24	pos.	0.32							pos.	0.18			neg.	0.37				
Ponderosa 5	neg.	0.17			neg.	0.28			neg.	0.26					neg.	0.17				
Ponderosa 6	pos.	0.23	pos.	0.34			pos.	0.23	pos.	0.13	pos.	0.15			neg.	0.42			neg.	0.31
Thomas 1	neg.	0.30	pos.	0.37							neg.	0.27								
Thomas 2																				
Thomas 3															neg.	0.39	pos.	0.32		
Thomas 4	neg.	0.28															pos.	0.42		
Thomas 6											neg.	0.52			neg.	0.54			neg.	0.56
Thomas 8	pos.	0.33					neg.	0.37	neg.	0.34					neg.	0.37				
Walker 1	neg.	0.28			neg.	0.19			neg.	0.24										
Walker 2			pos.	0.37	neg.	0.32	pos.	0.37	pos.	0.29	neg.	0.16			neg.	0.53			neg.	0.48
Webster 1	neg.	0.19	pos.	0.19	neg.	0.41					neg.	0.22							neg.	0.35
Webster 2	neg.	0.34	pos.	0.22	neg.	0.30					neg.	0.29			neg.	0.22	pos.	0.16		
Minimum		*0.17*		*0.16*		*0.16*		*0.23*		*0.13*		*0.15*		*0.67*		*0.16*		*0.14*		*0.31*

Table 7. Sign and tau of correlations between selected parameters and monthly pumpage volumes for City of Albuquerque drinking-water supply wells--Concluded

Well name	Dissolved solids Sign	Dissolved solids Tau	Calcium Sign	Calcium Tau	Sodium Sign	Sodium Tau	Bicarbonate Sign	Bicarbonate Tau	Sulfate Sign	Sulfate Tau	Chloride Sign	Chloride Tau	Silica Sign	Silica Tau	Arsenic Sign	Arsenic Tau	Field pH Sign	Field pH Tau	Temperature Sign	Temperature Tau
Maximum		*0.46*		*0.37*		*0.41*		*0.37*		*0.34*		*0.54*		*0.67*		*0.60*		*0.42*		*0.56*
Median		*0.28*		*0.32*		*0.29*		*0.37*		*0.26*		*0.22*		*0.67*		*0.38*		*0.17*		*0.39*
Number of correlations		*11*		*7*		*6*		*3*		*5*		*9*		*1*		*10*		*5*		*5*
Positive correlations	*3*		*7*		*1*		*2*		*2*		*3*		*0*		*1*		*5*		*0*	
Negative correlations	*8*		*0*		*5*		*1*		*3*		*6*		*1*		*9*		*0*		*5*	
Mountain Front region:																				
Lomas 1									neg.	0.24	neg.	0.25								
Lomas 5																				
Lomas 6																				
Love 1	neg.	0.31									neg.	0.37								
Love 3							pos.	0.29			neg.	0.45								
Love 4									pos.	0.26	neg.	0.31			neg.	0.43				
Love 5	neg.	0.26									neg.	0.32								
Love 6																				
Love 7	neg.	0.30									neg.	0.39								
Ponderosa 2	neg.	0.16					pos.	0.17			neg.	0.17								
Ponderosa 4	neg.	0.47			neg.	0.19			neg.	0.16	neg.	0.41			neg.	0.15	pos.	0.21		
Ridgecrest 1	neg.	0.43							neg.	0.49	neg.	0.26					pos.	0.27	pos.	0.42
Ridgecrest 2																	pos.	0.23	pos.	0.22
Ridgecrest 3							pos.	0.31			neg.	0.53								
Minimum		*0.16*				*0.19*		*0.17*		*0.16*		*0.17*				*0.15*		*0.21*		*0.22*
Maximum		*0.47*				*0.19*		*0.31*		*0.49*		*0.53*				*0.43*		*0.27*		*0.42*
Median		*0.31*				*0.19*		*0.29*		*0.25*		*0.35*				*0.29*		*0.23*		*0.32*
Number of correlations		*6*				*1*		*3*		*4*		*10*				*2*		*3*		*2*
Positive correlations	*0*				*0*		*3*		*1*		*0*				*0*		*3*		*2*	
Negative correlations	*6*				*1*		*0*		*3*		*10*				*2*		*0*		*0*	
All wells:																				
Minimum		*0.14*		*0.16*		*0.16*		*0.16*		*0.13*		*0.15*		*0.19*		*0.14*		*0.13*		*0.19*
Maximum		*0.47*		*0.55*		*0.41*		*0.50*		*0.49*		*0.54*		*0.67*		*0.60*		*0.52*		*0.59*
Median		*0.28*		*0.35*		*0.28*		*0.31*		*0.29*		*0.32*		*0.30*		*0.37*		*0.27*		*0.35*
Number of correlations		*29*		*20*		*14*		*25*		*29*		*32*		*10*		*25*		*19*		*26*
Positive correlations	*8*		*11*		*5*		*11*		*17*		*10*		*4*		*7*		*19*		*19*	
Negative correlations	*21*		*9*		*9*		*14*		*12*		*22*		*6*		*18*		*0*		*7*	

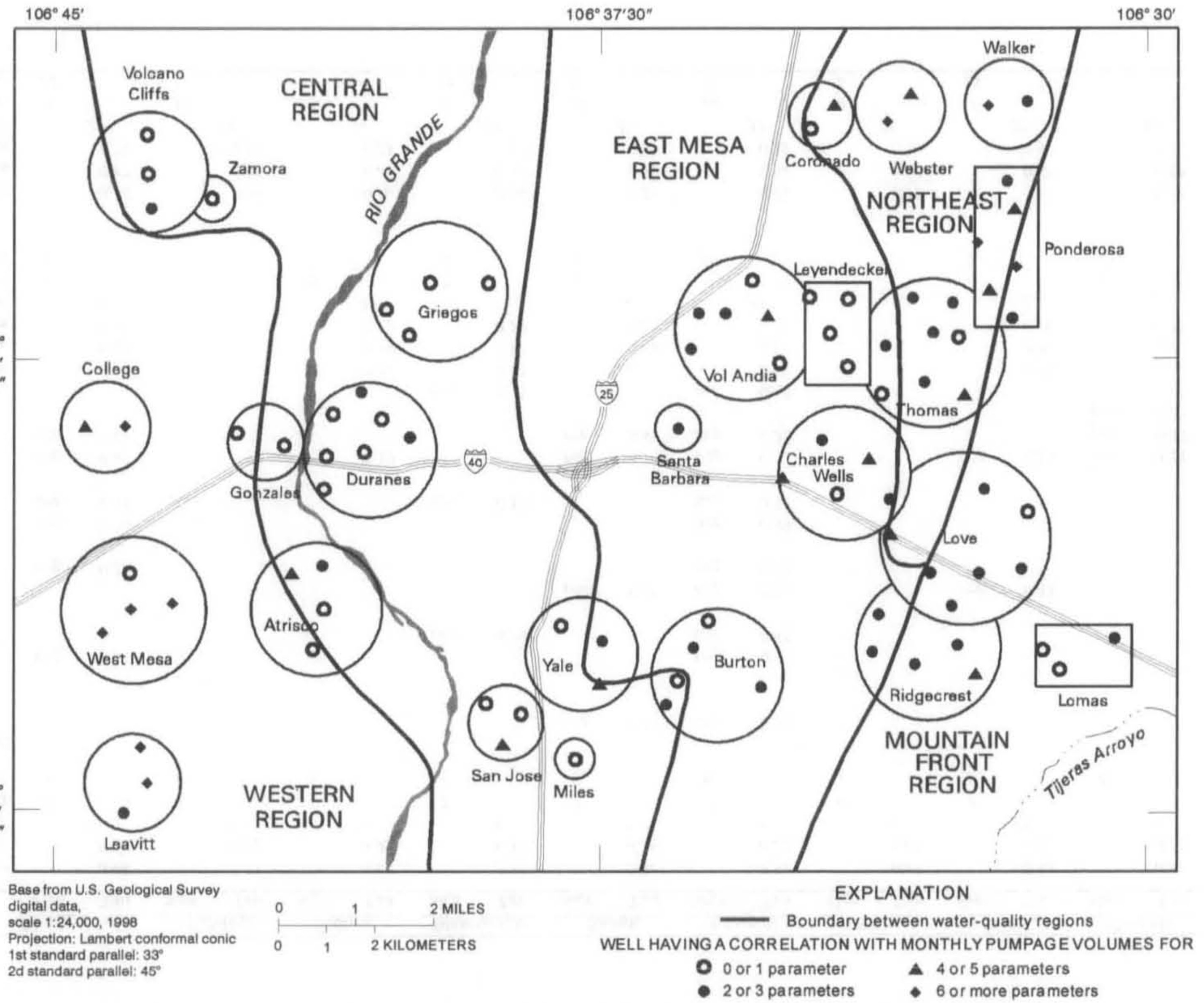


Figure 42. Number of parameters for which City of Albuquerque drinking-water supply wells have correlations with monthly pumpage volumes.

Table 8. Summary of variations in water quality among City of Albuquerque drinking-water supply wells
[IQR, interquartile range; y, yes; neg., negative; pos., positive]

Well name	Dissolved solids: IQR among 10 largest	Dissolved solids: Direction of trend	Dissolved solids: Sign of correlation with pumpage	Calcium: IQR among 10 largest	Calcium: Direction of trend	Calcium: Sign of correlation with pumpage	Sodium: IQR among 10 largest	Sodium: Direction of trend	Sodium: Sign of correlation with pumpage	Bicarbonate: IQR among 10 largest	Bicarbonate: Direction of trend	Bicarbonate: Sign of correlation with pumpage	Sulfate: IQR among 10 largest	Sulfate: Direction of trend	Sulfate: Sign of correlation with pumpage
Western region:															
Atrisco 1					up	neg.	y								
Gonzales 1									pos.					up	
College 1		up	neg.		down										
College 2		up			down	neg.			pos.	y		neg.		up	pos.
Leavitt 1		up	pos.		down	neg.					down	neg.		up	pos.
Leavitt 2			pos.		down		y						y	down	pos.
Leavitt 3					down		y		neg.				y	down	pos.
West Mesa 1	y		neg.		down	neg.	y		neg.	y	down	neg.	y	down	neg.
West Mesa 2							y					neg.		down	
West Mesa 3		up			down	neg.					down	neg.		up	pos.
West Mesa 4	y	up	pos.		down	neg.	y	up		y	down	neg.	y	up	pos.
Central region:															
Atrisco 2		up						up			up				
Atrisco 3		up			down				pos.				y		pos.
Atrisco 4		up			up	neg.					up		y	up	neg.
Burton 1		up												down	
Burton 4			neg.												
Duranes 1		up	neg.	y			y			y	up		y	up	neg.
Duranes 2											down	pos.			pos.
Duranes 3							y								
Duranes 4		up										neg.			
Duranes 5														down	
Duranes 6															
Duranes 7							y						y	down	
Gonzales 2		up	neg.											up	
Griegos 1		up		y						y				up	
Griegos 2	y									y				down	pos.
Griegos 3															
Griegos 4		up													
Miles Road 1		up						up						up	
San Jose 1	y	down	pos.	y	down	pos.					down	pos.	y	down	
San Jose 2		up										neg.		up	

Table 8. Summary of variations in water quality among City of Albuquerque drinking-water supply wells--Continued

	Dissolved solids			Calcium			Sodium			Bicarbonate			Sulfate		
Well name	IQR among 10 largest	Direction of trend	Sign of correlation with pumpage	IQR among 10 largest	Direction of trend	Sign of correlation with pumpage	IQR among 10 largest	Direction of trend	Sign of correlation with pumpage	IQR among 10 largest	Direction of trend	Sign of correlation with pumpage	IQR among 10 largest	Direction of trend	Sign of correlation with pumpage
San Jose 3		up												up	
Volcano Cliffs 1		up						up				pos.			
Volcano Cliffs 2		up			down									up	neg.
Volcano Cliffs 3		up			down									up	
Yale 2		up	neg.											up	neg.
Yale 3		up									up				
Zamora 1		up			down									up	
East Mesa region:															
Burton 2		up						up			up	neg.		up	
Burton 3														down	
Burton 5			neg.												
Charles Wells 1						neg.									pos.
Charles Wells 2		up								y	down				
Charles Wells 3		up									down	pos.			pos.
Charles Wells 4		up	pos.							y	down	pos.			pos.
Charles Wells 5					up				neg.					up	neg.
Leyendecker 1											down				
Leyendecker 2		up													
Leyendecker 3		up										neg.		up	
Leyendecker 4		up													pos.
Ridgecrest 4		up									down	pos.		down	
Ridgecrest 5														up	
Santa Barbara 1		up				pos.						neg.		up	
Thomas 5												neg.		up	
Thomas 7														up	
Vol Andia 1	y	up		y	up							neg.	y	up	
Vol Andia 2								down						up	
Vol Andia 3		up				pos.								up	
Vol Andia 4	y	up				pos.			pos.						
Vol Andia 5															pos.
Vol Andia 6		up				neg.					up			up	
Yale 1		up												up	

Table 8. Summary of variations in water quality among City of Albuquerque drinking-water supply wells--Continued

	Dissolved solids			Calcium			Sodium			Bicarbonate			Sulfate		
Well name	IQR among 10 largest	Direction of trend	Sign of correlation with pumpage	IQR among 10 largest	Direction of trend	Sign of correlation with pumpage	IQR among 10 largest	Direction of trend	Sign of correlation with pumpage	IQR among 10 largest	Direction of trend	Sign of correlation with pumpage	IQR among 10 largest	Direction of trend	Sign of correlation with pumpage
Northeast region:															
Coronado 1					down	pos.			pos.					up	
Coronado 2								up						up	
Love 8			neg.					up						up	
Ponderosa 1		up	neg.		down						up			up	
Ponderosa 3			pos.	y	down	pos.									
Ponderosa 5		up	neg.					up	neg.		up			up	neg.
Ponderosa 6			pos.		down	pos.						pos.		up	pos.
Thomas 1		up	neg.			pos.									
Thomas 2				y	down										
Thomas 3		up		y											
Thomas 4	y	up	neg.								up			up	
Thomas 6				y										up	
Thomas 8			pos.	y								neg.			neg.
Walker 1		up	neg.					up	neg.					up	neg.
Walker 2					down	pos.			neg			pos.		up	pos.
Webster 1		up	neg.		down	pos.		up	neg.		up				
Webster 2		up	neg.		down	pos.			neg.					up	
Mountain Front region:															
Lomas 1	y	up								y	down			up	neg.
Lomas 5		up									up				
Lomas 6	y	up								y	up			up	
Love 1			neg.												
Love 3								up			down	pos.			
Love 4		up													pos.
Love 5		up	neg.		up			up		y	down				
Love 6		up												down	
Love 7		up	neg.												
Ponderosa 2	y	up	neg.					up			down	pos.		up	
Ponderosa 4		up	neg.		up			up	neg.		down			up	neg.
Ridgecrest 1		up	neg.	y						y				up	neg.
Ridgecrest 2															
Ridgecrest 3		up										pos.			

Table 8. Summary of variations in water quality among City of Albuquerque drinking-water supply wells--Continued

Well name	Chloride: IQR among 10 largest	Chloride: Direction of trend	Chloride: Sign of correlation with pumpage	Silica: IQR among 10 largest	Silica: Direction of trend	Silica: Sign of correlation with pumpage	Arsenic: IQR among 10 largest	Arsenic: Direction of trend	Arsenic: Sign of correlation with pumpage	Field pH (standard units): IQR among 10 largest	Field pH (standard units): Direction of trend	Field pH (standard units): Sign of correlation with pumpage	Temperature (deg. C): IQR among 10 largest	Temperature (deg. C): Direction of trend	Temperature (deg. C): Sign of correlation with pumpage
Western region:															
Atrisco 1		down												down	
Gonzales 1		up												down	
College 1							y	down	pos.		down	pos.		down	pos.
College 2						neg.	y	down				pos.	y	up	pos.
Leavitt 1			neg.			pos.	y							up	pos.
Leavitt 2		down	pos.			neg.	y	down	pos.		down		y	down	pos.
Leavitt 3		down				neg.									
West Mesa 1		down				pos.	y		pos.			pos.	y	up	pos.
West Mesa 2		up					y	up							
West Mesa 3		up			up	pos.	y	down	neg.		up	pos.	y	up	pos.
West Mesa 4		up	pos.		up	pos.	y	up	pos.	y		pos	y	up	pos.
Central region:															
Atrisco 2		up						down						down	pos.
Atrisco 3		down	pos.					down		y				down	
Atrisco 4		up						down	pos.					down	pos.
Burton 1		up									down				
Burton 4		up							neg.						neg.
Duranes 1				y			y				down			down	
Duranes 2								down						down	
Duranes 3														down	
Duranes 4		down						down						down	
Duranes 5		down												down	
Duranes 6								down		y				down	
Duranes 7								down			down			down	
Gonzales 2															
Griegos 1				y				down						down	pos.
Griegos 2				y						y					
Griegos 3				y							down	pos.		down	
Griegos 4				y						y	down			down	pos.
Miles Road 1		up		y	up			up			down			up	
San Jose 1		down	pos.											down	pos.
San Jose 2		down						down			down			down	

Table 8. Summary of variations in water quality among City of Albuquerque drinking-water supply wells--Continued

	Chloride			Silica			Arsenic			Field pH (standard units)			Temperature (deg. C)		
Well name	**IQR among 10 largest**	**Direction of trend**	**Sign of correlation with pumpage**	**IQR among 10 largest**	**Direction of trend**	**Sign of correlation with pumpage**	**IQR among 10 largest**	**Direction of trend**	**Sign of correlation with pumpage**	**IQR among 10 largest**	**Direction of trend**	**Sign of correlation with pumpage**	**IQR among 10 largest**	**Direction of trend**	**Sign of correlation with pumpage**
San Jose 3		down					y	down			down			down	
Volcano Cliffs 1		down									down			down	
Volcano Cliffs 2		down							pos.		down			down	pos.
Volcano Cliffs 3								up			down			down	
Yale 2		up	neg.								down	pos.			
Yale 3		down		y	up						down				
Zamora 1											down				
East Mesa region:															
Burton 2		up	neg.												
Burton 3		down								y		pos.			
Burton 5									neg.						
Charles Wells 1		down	pos.							y				down	pos.
Charles Wells 2				y							down		y	down	
Charles Wells 3		up													pos.
Charles Wells 4														down	
Charles Wells 5		up	neg.						neg.						
Leyendecker 1														down	
Leyendecker 2		up									down			down	
Leyendecker 3		up									down			down	
Leyendecker 4		up									down			down	
Ridgecrest 4		up	neg.								down			down	
Ridgecrest 5						neg.			neg.						
Santa Barbara 1		up									down				neg.
Thomas 5		down							neg						
Thomas 7		down							neg.				y		
Vol'Andia 1		up				neg		down			down				
Vol Andia 2												pos.		down	
Vol Andia 3		up													pos.
Vol Andia 4			pos.									pos			pos.
Vol Andia 5		down	pos.												
Vol Andia 6		up						down			down			down	
Yale 1		up	neg.								down	pos.			

Table 8. Summary of variations in water quality among City of Albuquerque drinking-water supply wells--Concluded

	Chloride			Silica			Arsenic			Field pH (standard units)			Temperature (deg. C)		
Well name	IQR among 10 largest	Direction of trend	Sign of correlation with pumpage	IQR among 10 largest	Direction of trend	Sign of correlation with pumpage	IQR among 10 largest	Direction of trend	Sign of correlation with pumpage	IQR among 10 largest	Direction of trend	Sign of correlation with pumpage	IQR among 10 largest	Direction of trend	Sign of correlation with pumpage
Northeast region:															
Coronado 1	y	down	pos.					down	pos.			pos.		down	
Coronado 2		down						up							
Love 8	y		neg.	y		neg.			neg.						
Ponderosa 1	y										down	pos.	y	up	neg.
Ponderosa 3	y		pos.				y		neg.						
Ponderosa 5		up					y	down	neg.		down				
Ponderosa 6			pos.				y	up	neg.						neg.
Thomas 1		up	neg.							y	down				
Thomas 2		down			up					y					
Thomas 3									neg.		down	pos.		down	
Thomas 4	y									y	down	pos.			
Thomas 6	y	down	neg.						neg.				y		neg.
Thomas 8		up					y	down	neg.				y	down	
Walker 1	y	up						down							
Walker 2			neg.				y		neg.						neg.
Webster 1			neg.				y				down			up	neg.
Webster 2		up	neg.						neg.		down	pos.		down	
Mountain Front region:															
Lomas 1	y	up	neg.								down			up	
Lomas 5											down				
Lomas 6		up									down			down	
Love 1			neg.												
Love 3		up	neg.								down				
Love 4			neg.						neg.						
Love 5		up	neg.												
Love 6		up													
Love 7		up	neg.												
Ponderosa 2	y	up	neg.								down			up	
Ponderosa 4	y	up	neg.						neg.		down	pos.		up	
Ridgecrest 1			neg.							y	down	pos.		down	pos.
Ridgecrest 2											down	pos.			pos.
Ridgecrest 3			neg.												

However, the observation that seven wells show increases in water temperature with increasing pumpage while six wells show increases in sulfate and six wells show decreases in calcium with increasing pumpage could indicate that changes in hydraulic-head distribution from greater local pumping stresses often cause a greater contribution of water from deeper parts of the aquifer (see data for the 98th Street piezometer nest in table 4).

Central Region

The Volcano Cliffs wells and Zamora 1 show no large variabilities for any parameter. All four wells show downward trends in field pH and upward trends in dissolved-solids concentration, and three show downward trends in calcium concentration and water temperature and upward trends in sulfate concentration (table 8). Although these wells show similar patterns in water-quality variation, the reasons for these patterns are unknown. The time trends are not all consistent with a change either in the contribution of water from the Western region or from different depths of the aquifer. Specifically, although a decrease in field pH and temperature is consistent with a decreasing contribution of water either from the Western region or from greater depth within the aquifer, neither a decrease in calcium nor an increase in dissolved-solids concentration would be consistent with either process (table 3 and Sierra Vista data in table 4).

All four Griegos wells show large variability in silica concentration, and three (all except Griegos 3) show large variability in two or more parameters. Three of the wells (Griegos 1, 3, and 4) show trends in at least two parameters with time. All three show downward trends in water temperature, two show downward trends in field pH, and two show upward trends in dissolved-solids concentration (table 8). When compared to data from the Garfield nest, these trends (as well as the upward trend in sulfate and downward trend in arsenic in Griegos 1) could be consistent with a greater contribution of water from the shallow part of the aquifer with time, although the change in pH with depth is not known (table 4). A greater contribution of shallow water with time is consistent with the downward hydraulic-head gradients observed in the Garfield nest, the magnitude of which could increase as a result of regional drawdown from ground-water pumping at depth. In contrast, Griegos 2 shows only a downward trend in sulfate, the reason for which is uncertain. All four wells show correlation between just one parameter and monthly pumpage volume, implying that local pumping stresses are not very important (table 8).

A small group of wells in the southern part of the Central region (Miles 1, Yale 2, and Burton 1 and 4) show upward trends in chloride concentration with time (table 8). The chloride-concentration increases common to these wells may indicate that water-quality variation in all the wells results from the same process. Three of the wells also show upward trends in dissolved-solids concentration and downward trends in field pH. The increases in chloride and dissolved-solids concentrations in these wells may be associated with an increase in the contribution of deep ground water believed to be moving upward in the area because of a structural high at the southern end of the study area. The trends of increasing arsenic concentration and water temperature in Miles 1 appear to support this possibility. However, no piezometer nests are in this area from which vertical hydraulic-head distributions or changes in water quality with increasing depth could be obtained. If the increase in chloride in these wells with time was instead due to an increasing contribution of water from the nearby East Mesa region, dissolved-solids concentrations would be expected to decrease rather than increase (table 3). Two of the four wells in this group (Yale 2 and Burton 4) each show correlation between three or more parameters and monthly pumpage volume, indicating some effects from local pumpage in these wells; the other two wells show no correlations.

The remaining 15 wells in this region (Duranes 1-7, Gonzales 2, Atrisco 2-4, San Jose 1-3, and Yale 3) generally show fairly similar water-quality variations. Of these wells, 11 show large variability in one parameter or no parameters, 12 show trends in at least three parameters with time, and 12 show correlations between two or fewer parameters and monthly pumpage volume (table 8). Of the four wells that show large variability in two or more parameters (Atrisco 3, San Jose 1, and Duranes 1 and 7), all four have large variability in sulfate concentration and two have large variability in sodium concentration. Duranes 1 shows large variability in six parameters. Thirteen of the 15 wells in this group show downward trends in water temperature, 9 show downward trends in arsenic concentration, 9 show upward trends in dissolved-solids concentration, and 7 show downward trends in chloride concentration. When compared to water chemistry and hydraulic-head data for the West Bluff piezometer nest (table 4), all these trends could be consistent with an increasing contribution of water from the shallow compared with the middle part of the aquifer sampled. These trends do not appear consistent with either an increase or decrease in contribution of water from the Western region (which has larger dissolved-solids and arsenic concentrations) or directly from the Rio Grande (which has smaller dissolved-solids and arsenic concentrations) (tables 3 and 1). Other parameters have additional trends in most wells in this group, but they are not as widespread as the trends just discussed. The shallow depths to water in this area make effects from land use more likely than in many other parts of the study area. This could contribute to the variability and trends observed in some parameters. Because most wells show correlations between two or fewer parameters and monthly pumpage volume, local pumping stresses generally do not appear to have a large effect on the quality of water produced by wells in this area. The wells that appear to show the greatest effects from local pumping stresses are Atrisco 3 and 4 and San Jose 1.

East Mesa Region

Of the 24 wells in the East Mesa region, only 7 show large variability in any of the 10 parameters studied. Four of these wells (Thomas 7 and Charles Wells 1, 2, and 4) are near the boundary between the East Mesa and the Northeast regions and in an area of large drawdowns (about 100 feet since predevelopment; fig. 6). Two of these four wells show large variability in water temperature, two in bicarbonate concentration, and one each in field pH and silica concentration (table 8). With the exception of silica concentration (which shows large variability in the well farthest from the East Mesa-Northeast region boundary), variability in these parameters is consistent with varying contributions of water from the East Mesa compared with the Northeast region (table 3). Thomas 5 (also located along the East Mesa-Northeast region boundary) does not show large variability in any parameter, but does show a downward trend in chloride concentration, which is also observed in Thomas 7 and Charles Wells 1 and could indicate a decreasing contribution of water from the Northeast region with time (tables 3 and 8). Although Charles Wells 1, 2, and 4 all have downward trends in water temperature, all except Charles Wells 1 also have increasing trends in dissolved-solids concentration, so variability in these wells probably is not associated with a decrease in the contribution of Northeast region water with time. The trends observed in these wells could be consistent with a greater contribution of water from the shallow part of the aquifer, as shown by comparison to the water quality observed in the Del Sol Divider piezometer nest (table 4). However, vertical hydraulic-head gradients in this nest are consistent with the downward movement of water from the shallowest completion only during periods of high demand. The trends observed in Charles 3 and 5 also are consistent with a greater contribution of shallow water, which could be facilitated by head distributions changing in the shallow part of the aquifer because of drawdown of the regional water table. Several of these wells (Thomas 5 and Charles 1 and 3-5) show correlation between at least two parameters and monthly pumpage volume (table 8), indicating that local pumping stresses may have a substantial effect on water quality in these wells. These correlations occur for different parameters depending on the well and are not always in similar directions for the same parameter.

None of the Leyendecker wells show large variability in any parameter, indicating that water-quality variations are not large compared with those in other wells, but the four wells show some similar trends with time (table 8). All four wells show decreasing trends in water temperature, three show decreasing trends in field pH, and three show increasing trends in chloride and dissolved-solids concentrations. No water-quality data are available for the shallow completion of the Sister Cities piezometer nest (table 4), so whether the observed trends could be consistent with a change in the contribution of water from different depths of the aquifer cannot be determined. Although the increases in dissolved-solids and chloride concentrations are consistent with an increase in the contribution of water from the Northeast region (table 3), this does not seem likely because of the decrease in water temperature and the relatively long distance of the Leyendecker wells from the Northeast region. Two of these wells (Leyendecker 1 and 2) show no correlation between any water-quality parameters and monthly pumpage volume; two (Leyendecker 3 and 4) show a correlation for only one parameter each (table 8). Therefore, local pumping stresses do not appear to have a large effect on the quality of water pumped from any of these wells.

Northeast Region

Of the 17 wells in the Northeast region, data show that 15 wells have large variability in at least one parameter, 16 have temporal trends in at least two parameters, and 13 have correlations between at least three parameters and monthly pumpage volume. The largest variabilities are for chloride (seven wells) and arsenic (six wells), which are two of several parameters that show large differences both with depth in the Nor Este and Sister Cities piezometer nests (table 4) and between the Northeast region and surrounding water-quality regions (table 3). The wide variability and numerous trends in water quality in wells in the Northeast region show substantial changes in the response of the aquifer to pumping stresses in this area with time, even though not all wells are responding in the same ways, as discussed below.

Parameters that commonly showed trends with time include sulfate (upward trends in 11 wells), chloride (5 upward and 4 downward trends), dissolved solids (8 upward trends), and field pH (7 downward trends) (table 8); however, all 10 parameters investigated showed a trend in at least one well in the Northeast region. As with chloride concentration, trend direction for a single parameter is not always the same for all wells in which a trend occurs. Therefore, individual wells within the region appear to be affected differently by the changing hydraulic-head distributions caused by pumping stresses. For example, in Coronado 1, chloride and arsenic concentrations and water temperature are trending downward with time, whereas sulfate concentration is trending upward (table 8). This well is located near the boundary between the Northeast and East Mesa regions, and the changes observed are consistent with an increasing contribution of water from the East Mesa region with time, possibly from drawdown in the area. In contrast, in Ponderosa 6, sulfate and arsenic concentrations are trending upward, whereas calcium concentration is trending downward. Although these trends are not all consistent with an increasing contribution of water from outside the Northeast region, they perhaps are consistent with an increase in the contribution of water from deeper in the aquifer in this general area, as indicated by chemical data for the Sister Cities piezometer nest (table 4). If ground water with elevated dissolved solids is moving upward in this area (either due to a structural high or to upwelling along faults), as would be consistent with vertical hydraulic-head gradients, the distribution of such water in the aquifer could change with time as a result of regional changes in hydraulic heads in the area. Also, an increasing contribution of deeper water to an individual well might result from a change in the distribution of hydraulic heads adjacent to the well or from screen plugging.

As with temporal trends, most wells in the Northeast region show correlations between several parameters and monthly pumpage volumes. However, these correlations are not always in similar directions for the same parameter in all wells, indicating that although local pumping stresses appear to be important, aquifer responses to such stresses are variable in the region. This observation could help explain why temporal trends are also generally variable among wells in the region. If variations in water quality are controlled mostly by local pumping stresses, several wells spread out across the region are not expected to show similar patterns of variation. Of the wells that do show correlations between dissolved-solids concentrations and monthly pumpage volume, most tend to show decreasing concentrations of these parameters with increases in pumpage volume. Therefore, greater local pumping stresses typically appear to result in the production of water with smaller dissolved-solids concentrations.

Mountain Front Region

Ponderosa 2 and 4 are close to the boundary between the Mountain Front and Northeast regions and show similar water-quality variations. Both wells show large variability in chloride; Ponderosa 2 also shows large variability in dissolved solids. Also, both wells show temporal trends in 7 of the 10 parameters investigated (dissolved solids, chloride, sulfate, bicarbonate, sodium, field pH, and water temperature), and the directions of the trends agree between wells (table 8). Ponderosa 4 also shows an upward trend in calcium. With the possible exception of water temperature, trends in these parameters are consistent with changing contributions of water from the Mountain Front compared with the Northeast region (table 3 shows that the median values of these parameters differ substantially for the two regions). The directions of all trends except that in bicarbonate are consistent with an increasing contribution of water from the Northeast region with time, which could result from a greater component of easterly ground-water flow caused by water-table drawdown in this area. In contrast, correlations between concentration and monthly pumpage volume for the two wells generally indicate that the larger the pumping volume, the larger the contribution of water from the Mountain Front region. For example, both wells show negative correlations between dissolved-solids and chloride concentrations and monthly pumpage volume (table 8). Ponderosa 4 shows correlations between the values of several additional parameters and monthly pumpage volume, all of which are consistent with a greater contribution of Mountain Front water. The reason for a greater contribution of Mountain Front water with greater pumping stress is not certain, but could involve a larger increase in the head gradient in parts of the aquifer containing Mountain Front water. The role that water-quality differences with depth might play in this area is not known because no water-quality data are available for nearby piezometer nests.

Most wells in the southern part of the Mountain Front region do not show large variability in any parameters but do show some temporal trends and correlations with monthly pumpage volumes. The three wells that show large variability in two or more parameters (Lomas 1 and 6 and Ridgecrest 1) are all relatively close to Tijeras Arroyo. All three wells show large variability in bicarbonate concentration, and Lomas 1 and 6 also show large variability in dissolved-solids concentration (table 8). All three wells show upward trends in dissolved-solids and sulfate concentrations and downward trends in field pH with respect to time, whereas two of the three show upward trends in chloride concentrations, and two show downward trends in water temperature with respect to time (table 8). Although the other well close to Tijeras Arroyo, Lomas 5, does not show large variability in any parameter, it shows an upward trend in dissolved-solids concentration and a downward trend in field pH with time. The similarities among these four wells suggest that the variability and time trends in all of them could be associated with the same process. Because of their proximity to Tijeras Arroyo, which has water with large dissolved-solids, chloride, sulfate, and bicarbonate concentrations relative to ground water typical of the Mountain Front region (tables 1 and 3), variations in water quality for these wells could be associated with water that recharged through Tijeras Arroyo. No piezometer nests are nearby from which information on vertical head gradients or differences in water quality with depth could be obtained. The numbers of parameters for which these wells show correlations with monthly pumpage, as well as the parameters themselves, differ among the four wells (table 8), indicating different responses to localized pumping stresses. Lomas 1 and Ridgecrest 1 (the two wells that show correlations with monthly pumpage), however, show a decrease in sulfate and chloride with increasing pumpage volumes, which could indicate that any contribution of recharge water from Tijeras Arroyo decreases with greater local pumping stress.

Although they show large variability in no more than one parameter, several additional wells in the southern part of the Mountain Front region (Love 1 and 3-7 and Ridgecrest 2 and 3) show temporal trends and (or) correlation with monthly pumpage volume for at least two parameters (table 8). The parameters that most commonly show temporal trends and (or) correlation with monthly pumpage volumes among these wells are dissolved-solids concentration, chloride concentration, and field pH. Dissolved-solids and chloride trends are always upward; similarly, field pH trends with time are always downward. The reasons for these trends and correlations are unknown, in part because no chemical data are available for discrete depths in this area. However, the observed trends could result from a greater component of easterly ground-water flow caused by drawdown of the water table in this area, which would tend to bring in water with larger dissolved-solids and chloride concentrations (figs. 17 and 18). Most wells in this area show correlations between at least two chemical parameters and monthly pumpage, indicating that local pumping stresses commonly can affect delivered water chemistry. For the six wells (Love 1, 3-5, and 7 and Ridgecrest 3) that show correlations between dissolved-solids and (or) chloride concentrations and monthly pumpage volume, the correlations show decreases in these parameters with increasing pumpage volume.

Summary

The greatest variability in water quality per well (with respect to IQR's, time trends, and correlation with pumping volumes) appears to be primarily in the Northeast and Western regions. This observation is consistent with relatively large water-quality differences observed with depth in piezometer nests in these areas, as well as large differences observed between these regions and their adjacent water-quality regions. The correlations between multiple parameters and monthly pumpage volumes for wells in these areas imply that local pumping stresses are an important factor in the variation. Such stresses tend to act on a shorter time scale than regional stresses, such as overall decline of the potentiometric surface, which tend to result in monotonic changes across longer time scales.

Wells in the Mountain Front, East Mesa, and Central regions show a relatively small incidence of large variability per well compared with wells in the Northeast and Western regions, probably because differences in water quality with depth and differences in water quality among these adjacent regions are smaller (tables 3 and 4). The East Mesa and Central regions also show substantially fewer correlations between parameters and monthly pumpage volumes, indicating that local pumping stresses probably are not particularly significant with regard to the quality of water pumped in these areas. However, trends in water-quality parameters are numerous and widespread in all three of these regions. Such numerous monotonic changes in water quality across the entire study area suggest that at least one factor contributing to time trends could be a change that affects most of the hydrologic system, such as decline of the regional potentiometric surface.

Effects of Accounting for Exogenous Variables in Temporal Trend Analysis

In an attempt to better determine major factors causing the temporal trends observed in the water quality of City drinking-water supply wells, an effort was made to identify potential factors that could be quantified and used in statistical tests. One such quantifiable factor is pumped volume per unit time by well, as discussed in the section, "Correlations between water quality and monthly pumpage volumes." Other potential factors include water-level drawdown, extent of screen plugging, changes in the depths at which pumps are set in individual wells, and seasonality in the weather. Data for localized drawdown, such as in the area of an individual well field, were judged to be too sparse and too inaccurate for use in statistical testing. Although the City of Albuquerque did collect water-level data for most of its wells at fairly regular intervals between 1988 and 1997, these data generally were collected when a well had been unused for only short periods and when other nearby wells continued to be pumped. Therefore, the data probably do not accurately represent static conditions in the aquifer. Data on the extent of screen plugging are also too sparse to be used in statistical testing because observations do not exist for a large number of wells at regular time intervals (Thorn, 2000). Changes in the depths at which pumps are set were judged to be unimportant because step changes were rarely observed in the distributions of water-quality data with time. If the depths of pump settings were important, water-quality data would be expected to change in a stepwise fashion between samples taken before and after a setting change. Seasonality in the weather also was judged to be unimportant because ground water produced by City drinking-water supply wells generally comes from deep within the aquifer and cannot reasonably be expected to be affected by seasonal changes in weather. Any seasonality observed in water-quality data are therefore associated with seasonal operation of the wells, in particular volumes of ground water pumped as a result of changes in seasonal demands.

Because monthly pumpage volumes appeared to be the only major potential factor in temporal trends that was accurately quantifiable, this was the only exogenous variable that could be tested for its effect on trends. Correlation tests had already shown significant relations between monthly pumpage volumes and selected water-quality parameters. A Mann-Kendall test performed on the residuals of the LOWESS curve of parameter value on monthly pumpage was used to look for temporal trends after variability in parameter values resulting from pumpage had been accounted for. If this test showed temporal trends (significant at the 0.05 level) that were not previously detected, this result would indicate that variation in pumpage had masked these trends, which then must be due to some other factor. If this test showed the same trends even after the effects of monthly pumpage on parameter values had been accounted for, this result would indicate that although pumpage did not mask these trends, they are nevertheless due largely to some other factor. Finally, if this test showed that trends that were significant when the effects of pumpage were unaccounted for were no longer significant once pumpage was taken into account, this result might indicate relations both between parameter value and pumpage and between pumpage and time that contributed to the trend in the parameter value.

To focus on wells with the largest changes in water quality, those wells with trend magnitudes in the upper 10 percent for at least one of the 10 major parameters studied were selected for the Mann-Kendall test on LOWESS residuals of parameter values against pumpage. This process resulted in the selection of 25 wells in 16 different well fields. The Mann-Kendall test on LOWESS residuals was performed for each well for only those parameters that showed statistically significant correlations between parameter value and pumpage. One well (Zamora 1) was dropped from the group of wells originally selected for testing because no parameters showed significant correlations with pumpage (table 9).

Of the 81 individual tests performed, p-values increased in 40, remained the same in 28, and decreased in 13 (table 9). In no test did a p-value decrease from greater than 0.05 to less than 0.05. These results indicate that in most wells variability in concentrations due to variability in pumpage did not mask existing temporal trends. Eleven wells showed an increase in p-value from less than 0.05 to greater than 0.05 for at least one parameter, indicating that relations between concentration and pumpage and between pumpage and time might be a large factor in the existence of trends in these wells. For example, in West Mesa 4, the p-value for a trend in arsenic concentration increased from <0.01 (representing a statistically strong relation with time) to 0.87 (representing a clear lack of relation with time) when the effects of the correlation between arsenic concentration and pumpage were removed. For this well, a positive correlation between arsenic concentration and monthly pumpage volume indicates that larger arsenic concentrations are associated with greater pumpage per unit time. Calculation of Kendall's tau between monthly pumpage volume and time indicates that pumpage increased during the period of study (p-value of <0.01). Therefore, the increase in arsenic concentration with time in West Mesa 4 probably resulted from a consistent increase in pumpage during the period of study.

Overall, calculation of the Mann-Kendall test on LOWESS residuals of parameter values against pumpage indicated that variability in pumping rates generally did not result in failure to detect temporal trends that otherwise would have been evident. The common increases in p-values for trends when the relation between parameter value and pumpage is taken into account indicate that this relation might be a contributing factor to the temporal trend in several cases. The contribution of pumpage variability to temporal trends appears to emphasize the importance of local pumping stresses (and, therefore, alteration of hydraulic-head distributions local to the well) in the variability of water quality in many individual wells.

SUMMARY OF IMPLICATIONS FOR THE GROUND-WATER FLOW SYSTEM

The distributions of water quality and hydraulic head across the study area provide important information about the ground-water flow system of the region. Plots of several major parameters demonstrate substantial water-quality differences both areally and with depth in the aquifer. Despite differences in water quality with depth, areal patterns are evident in water quality for wells completed in the part of the aquifer where City drinking-water supply wells are screened. These areal patterns enable delineation of regions of similar water quality that are consistent with the water-quality zones defined as part of a basinwide study of environmental tracers. The orientation of the water-quality regions indicates that ground-water flow through the study area has historically been oriented primarily north to south. Predevelopment hydraulic-head maps show a stronger component of westerly ground-water flow than is indicated by the water-quality regions. This lack of correspondence could be a factor of the different depths and (or) time scales represented by water quality (thousands of years) in comparison with the hydraulic-head maps (perhaps the past few hundred years).

Chemical characteristics of the water-quality regions defined for this study are consistent with the distinct sources of recharge indicated by the basinwide study of environmental tracers. The generally dilute waters of the Mountain Front region are consistent with mountain-front recharge along the Sandia Mountains and localized influence from infiltration through Tijeras Arroyo. Anion ratios and other chemical characteristics of the Central and East Mesa regions are consistent with seepage through the Rio Grande as the primary source of recharge. The large values of most constituents in water of the Western region are consistent with the older waters sourced from the area of the Jemez Mountains. In the Northeast region, the elevated concentrations of many chemical constituents appear to be associated with a source of water having large dissolved solids. The distribution of several chemical parameters both areally and with depth indicates that this mineralized water likely has moved upward from depth in the aquifer either along faults or from a bedrock high just north of the study area.

Table 9. Comparison of p-values for temporal trends before and after accounting for the effects of monthly pumpage volumes in City of Albuquerque drinking-water supply wells

[Old, before accounting for effects of pumpage; new, after accounting for effects of pumpage; <, less than]

Well name	Dissolved solids		Calcium		Sodium		Bicarbonate		Sulfate		Chloride		Silica		Arsenic		Field pH		Temperature	
	Old	New	Old	New	Old	New	Old	New	Old	New	Old	New	Old	New	Old	New	Old	New	Old	New
Atrisco 4			<0.01	0.08					<0.01	<0.01					<0.01	0.02			<0.01	<0.01
Charles Wells 5					0.34	0.39			<0.01	0.053	<0.01	0.01			0.45	0.23				
Duranes 1	<0.01	<0.01							<0.01	<0.01										
Gonzales 1					0.30	0.16														
Griegos 1																			<0.01	<0.01
Griegos 3																	<0.01	0.26		
Griegos 4																			<0.01	0.01
Leavitt 2	0.22	0.33							0.03	0.51	0.01	0.66	0.89	0.65	<0.01	<0.01			<0.01	0.12
Lomas 1									<0.01	<0.01	<0.01	<0.01								
Ponderosa 2	<0.01	<0.01					<0.01	<0.01			<0.01	<0.01								
Ponderosa 3	0.28	0.40	<0.01	0.02							0.34	0.76			0.91	0.26				
Ponderosa 4	<0.01	<0.01			<0.01	0.08			<0.01	0.08	<0.01	<0.01			0.32	0.80	<0.01	<0.01		
Ridgecrest 1	0.02	0.56							0.01	0.18	0.87	0.07					<0.01	<0.01	0.04	0.97
San Jose 1	<0.01	<0.01	<0.01	<0.01			<0.01	0.01			<0.01	<0.01							<0.01	<0.01
Thomas 3															0.06	0.46	<0.01	<0.01		

Table 9. Comparison of p-values for temporal trends before and after accounting for the effects of monthly pumpage volumes in City of Albuquerque drinking-water supply wells--Concluded

Well name	Dissolved solids		Calcium		Sodium		Bicarbonate		Sulfate		Chloride		Silica		Arsenic		Field pH		Temper-ature	
	Old	New	Old	New	Old	New	Old	New	Old	New	Old	New	Old	New	Old	New	Old	New	Old	New
Thomas 4	<0.01	0.03															<0.01	0.06		
Thomas 6											<0.01	<0.01			0.73	0.69			0.69	0.37
Thomas 8	0.69	1.0					0.18	0.28	0.67	0.26					<0.01	<0.01				
Vol Andia 1							0.05	0.44					0.21	1.0						
Vol Andia 2																	0.26	0.89		
Volcano Cliffs 1							0.77	0.52												
Walker 1	<0.01	<0.01			0.02	0.11			<0.01	<0.01										
West Mesa 1	0.22	0.21	<0.01	<0.01	0.22	0.08	<0.01	<0.01	0.02	0.39			0.33	0.98	0.43	0.72	0.92	0.28	<0.01	<0.01
West Mesa 4	<0.01	<0.01	<0.01	0.03			<0.01	0.07	<0.01	0.09	<0.01	0.03	0.03	0.02	<0.01	0.87	0.06	0.58	<0.01	0.06

Water-quality data for deep piezometer nests indicate that in most parts of the study area, concentrations of dissolved solids, sodium, sulfate, chloride, and arsenic increase with depth, suggesting a general degradation in water quality with increasing depth. The degradation in water quality with depth could be related to longer contact times between ground water and aquifer materials for deeper flow paths or in some cases related to the upwelling of very deep water. In contrast, data for the Del Sol Divider and Garfield piezometer nests indicate that in some areas shallow ground water can be of poorer quality than deeper water because of contributions from local recharge that has been affected by evapotranspiration or contamination. The substantial differences in water quality with depth observed in most piezometer nests indicate that water in the aquifer generally is not well mixed over large depth intervals, which could be the result of substantially larger horizontal than vertical hydraulic conductivities (greater rates of horizontal than vertical ground-water movement).

Hydraulic-head data for the piezometer nests indicate that vertical head gradients differ in direction and magnitude across the study area. In the Central, Western, and Mountain Front regions, hydraulic-head gradients are downward, whereas in the East Mesa and Northeast regions, the gradients are upward. Most of the largest vertical gradients are in the Western and Mountain Front regions. Even in areas of large vertical gradients, differences in water quality with depth indicate that ground water often is not well mixed.

Hydraulic-head data for the piezometer nests also indicate the depths of the greatest effects of ground-water withdrawals on head. In the 98th Street, Sierra Vista, and Matheson Park piezometer nests, water-level variations at the water table do not seem to be related to those in deeper zones, probably because of relatively small vertical hydraulic conductivities in these areas. In most piezometers screened below the water table, water levels respond clearly to seasonal variations in ground-water withdrawals. Water levels decline from about April through July and increase from about September through January. Water levels seem to be declining in most piezometers at a rate less than 1 foot per year.

Because water quality differs both areally and with depth across the study area and ground-water withdrawals alter hydraulic-head distributions and ground-water flow directions, individual wells are expected to show variations in water quality with time. Each of the 10 parameters investigated shows temporal trends in water for 5 to 57 wells. Dissolved-solids, chloride, sulfate, sodium, and silica concentrations show more increasing than decreasing trends; bicarbonate, calcium, and arsenic concentrations, field pH, and water temperature show more decreasing than increasing trends. The median magnitudes of most of these trends over a 1-year period are not particularly large (the changes in concentration of all chemical constituents except dissolved solids are less than 1.0 mg/L), indicating no substantial regional changes in water quality during this time period. The magnitudes for a few individual wells, though, are significant (such as the upward chloride trend of 3.7 mg/L in Ponderosa 4 over a 1-year period).

Each parameter investigated shows correlations with monthly pumpage volume for 10 to 32 wells. Sulfate and calcium concentrations, field pH, and water temperature show more positive than negative correlations with monthly pumpage volume; dissolved-solids, chloride, bicarbonate, sodium, silica, and arsenic concentrations show more negative than positive correlations with pumpage volume. An increase in pumpage in an individual well appears to increase the contribution of water from shallower parts of the aquifer in some areas and from deeper parts in others.

Patterns observed in water-quality variation can indicate how the aquifer in different areas is responding to stresses induced by ground-water pumpage. Water-quality variability has been shown to be greater in some parts of the study area than others. Per well, the Western region has the highest incidence of large variability, the largest number of temporal trends, and the largest number of correlations with monthly pumpage volumes. Per well, the Northeast region also has a high incidence of large variability, a relatively large number of temporal trends, and a large number of correlations with monthly pumpage volumes. In both regions, local pumping stresses appear to be an important factor in large water-quality variations. Also, in both regions large water-quality differences are known to exist with depth and relative to adjacent water-quality regions. Per well, the East Mesa region has the lowest incidence of large variability, the smallest number of temporal trends, and a relatively small number of correlations with monthly pumpage volumes. Even in this region, the average number of parameters showing a temporal trend per well is 3.2. Therefore, the substantial number of monotonic changes in water quality observed in most wells in the study area, combined with the relatively small number of correlations with monthly pumpage volumes in some regions, implies that a factor that affects essentially all wells, such as regional drawdown of the water table, could be important in causing the observed water-quality variation.

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